FEDERAL AVIATION ADMINISTRATION

Flight Standards Service

Highest Operational Safety Standards

Decision Support System (DSS) Requirements Study

Sponsored by: AAR-424

(FAA CONTRACT #DTFA0300F20134)

RICOMM Systems, Inc.

Date: April 16, 2001

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Table of Contents

Decision Support System Requirements Study

1. Executive Summary

A. *Background*

In a 1997 report, issued by a *White House Commission on Aviation Safety*, the FAA was asked to become more vigorous in its application of high standards for the certification of new aviation businesses and in its surveillance of existing regulated entities. Specifically, the FAA was asked to establish a goal of 80% reduction in the U.S. aviation accident rate by the Year 2007. The FAA responded to the Commission's challenge by creating a program initiative called *Safer Skies* and adopted a new business paradigm called the *System Safety Approach*, which it employs to manage the following certificated entities:

Part 91 General Aviation
Part 121 Air Carriers
Part 129 Foreign Operators
Part 135 Commuter and On-demand Operators
Part 141 Pilot Schools
Part 142 Training Centers
Part 145 Repair Stations
Part 147 Maintenance Technician Schools
Part 183 Designees

The *System Safety Approach* is a new conceptual approach for assuring the safe operation of certificated entities that goes well beyond merely ensuring that the regulated entities are complying with existing regulations as the sole means to determine a certificated entity's operational safety status. With the *System Safety Approach*, FAA inspection and surveillance activities focus on locating defects in the systems or business processes of certificated entities and all petitioners for new certificates.

Aviation Flight Standards (AFS) executes the business processes attendant to the FAA's *System Safety Approach*, and it also delivers mission support for the new business paradigm. Mission support of the *System Safety Approach* is totally dependent upon the existence of valid performance data for each certificated entity. At present, AFS has created, and maintains, more than two trillion bytes of performance and safety-related data, and the volume of data is increasing with each passing day. Moreover, the *System Safety Approach* will require AFS inspector personnel to analyze an ever-increasing amount of performance and safety-related data, if the goals and objectives of the Safer Skies Program are to be realized. This would suggest that AFS inspector and management personnel need a tool (i.e., a decision support system) to help analyze the volume of data generated by the new business paradigm. As a consequence of this concern, this Study was commissioned to help the FAA determine if such a tool is really needed.

B. *DSS Study Goals/Objectives*

The Study's major goals and objectives are:

Goals:

1. Perform a needs assessment for a decision support system (DSS) capability to support Aviation Flight Standards' new business paradigm – the *System Safety Approach*.

2. Define the system requirements for a DSS.

3. Determine if the *Safety Performance Analysis System* (*SPAS*) is an appropriate application delivery platform for an enterprise-wide DSS.

4. Recommend a construct for a decision support system (DSS), if such a system is needed.

***Objectives*:**

5. Develop a thorough understanding of AFS's four (4) business processes (i.e., inspection, investigation, surveillance, and oversight of certificated entities).

2. Produce a report describing AFS's business processes and the operational implications of the *System Safety Approach*.

3. Develop a questionnaire and use it to conduct interviews with the following staff members:
    1. AFS 900
    2. FSDO
    3. CMO Headquarters
    4. Principals
    5. ASIs
    6. SPAS Development team

4. Generate a report documenting our findings and issues, conclusions, and recommendations regarding AFS's need for an enterprise-wide DSS to help improve decision making.

5. Research and produce three (3) case studies of DSS implementations, one of which will be aviation-related.

C. *The Process*

Listed below are activities we undertook to satisfy the goals and objectives of this Study and generate this report.

- Reviewed the current Flight Standards' handbooks
- Wrote a report describing AFS's business processes and the *System Safety Approach*.

- Developed a DSS questionnaire that consisted of 26 questions, divided across the following three subcategories:
  - The System Safety Approach & ATOS
  - SPAS Version II and Version III
  - Desirable DSS capabilities

- Interviewed the following members of the Flight Standards organization:
  - AFS 900
  - FSDO
  - POIs, PMIs, DEPMs, and ORAs
  - CMO for one major airline
  - CMT members for three major airlines
  - the ATOS Continuous Application Development Team
  - the SPAS Development Team
  - the SPAS Program Manager

  To encourage a free exchange of information and ideas, survey participants were told that only summaries of questionnaires would be produced.

- Researched the current state of DSS Technology. *(The results of that effort are included in this report.)*

- Recommended a conceptual framework for a DSS capability. *(Please see the DSS Research and Recommendations sections for more details.)*

- Generated this report summarizing the study's findings, issues, conclusions, and recommendations.

- Researched the use of decision support systems in aviation and two other vertical industries. To that end, there is a case study located in the appendices regarding an aircraft fleet maintenance management DSS that is being used by Air Canada. The system was developed by Canada's National Research Council. Air Canada was selected as the *beta* test carrier because of the size and relative age of its fleet. *(Please see Case Study #1, in Appendix C, for more details)*

D. ***Findings and Issues***

The following are the major findings and issues that surfaced over the course of this Study:

***Findings*:**

- As an organization, AFS is awash in safety-related and performance data. SPAS alone has more than one trillion bytes of such information, and there are several other databases that contain even more.

- No single entity is responsible for executing control over these vast amounts of data so, not surprisingly, anarchy reigns when it comes to applying industry-standard data management techniques.

- CMO, CMT, principals, and inspector personnel believe that, in many instances, automated systems have helped them get their jobs done and, as a group, they feel left out of the loop.

- There is very little confidence that the *System Safety Approach*, as it is currently constituted, will be successful. The belief is that AFS is doing the *right things wrong* in the way it now conducts business.

- There are insufficient resources to adequately address SAI and EPI program initiatives as they were envisaged at program inception.

- There is a real need for a robust data analysis tool or capability that will make it less difficult to track and cross-correlate certificate-holders performance data accurately.

- The survey participants said the following DSS system features or attributes are most important. That is, these are the capabilities that have the highest degree of utility for them.

  - Workload balancing and scheduling
  - Online analytical processing (OLAP) tool
  - Model support (forecasting, optimization, and simulation)
  - Expert System Shell (identification of alternatives)
  - An enterprise-wide solution

  It was also their view that CMOs, ORAs, principals, and ASIs would benefit most from a DSS.

Issues:

- EPI data is not available until an EPI is completed, which can take a considerable amount of time.

- The physical and meta-data are not controlled. This has caused data quality and integrity problems. Too many synonyms exist among the agency's databases, which cause problems to day and these problems will only increase in the future.

- Field personnel feel as though their input about what capabilities should be designed into the systems that support them are not sought or heeded when those views are expressed.

- How will ACOSM's be used in the future, and should it be integrated, as a model, with a DSS?

- Who is the customer for the DSS?

- Is there sufficient robustness in AFS's IT infrastructure to support an enterprise-wide DSS?

E. *Conclusions*

- ATOS performance measures (PM) and performance indicators (PI) are flawed because each PM or PI represents observed behavior, rather than a computed value. This means that a PM or PI has very little value as a predictor of future performance.

- To effectively harvest the intrinsic value of the vast amount of safety-related and performance data AFS has amassed, responsibility for data administration and management of mission-critical databases should be vested with a single organizational entity.

- Because the number of extant database synonyms is so high, staff must now waste time entering important data multiple times. Moreover, database synonyms are often the source for bad or inaccurate data being used for decision making or generating official responses to inquiries.

- The *System Safety Approach* is not being administered in a consistent manner. A DSS could help ensure that at least the process is being faithfully and consistently followed across all geographic regions.

- AFS management needs access to a system framework that is capable of providing answers to questions without concern for the information media type, i.e., text, numerical raw data, standard computer reports, forecasts from simulation models, video, audio, et al. Equally important, is the need to have confidence in the source of information and the methods used to harvest it. A DSS could be the answer.

F. *Recommendations*

- Centralize the control of all mission-critical databases under one organizational entity.

- Initiate a project to develop meta-data describing the organization's data.

- Delay the implementation of a DSS until all data problems have been resolved. But alternatively, consider moving forward with a data warehousing project.

- Study the heuristics of decision making in the organization. Then determine if changes should be made. Only then, after cleaning up the organization's data, should a search for a DSS begin.

- Conduct team-building sessions to foster cooperation between system users and the system providers.

- Develop a 3 to 5 year , objectives-based, IT strategic plan that is closely aligned with AFS's business plans.

2. DSS Study Goals/Objectives

As a project, the DSS Requirements Study had the following set of goals and objectives.

***Goals*:**

1. Canvas the Flight Standards organization to understand its view regarding the need for a DSS that will aid the organization in the execution of its new business paradigm – the *System Safety Approach*.

2. Define and document a set of system requirements to guide and focus future discussions, within AFS, regarding the appropriate course of action to follow for the development of an enterprise-wide DSS for AFS inspector and management personnel.

3. Determine if SPAS is a suitable DSS delivery platform for an AFS DSS capability.

Objectives:

1. Review the current Flight Standards handbooks to gain a better understanding of the following four business processes: certification, surveillance, investigation and oversight.

2. Increase our knowledge of the current system safety efforts that are ongoing within AFS, with particular emphasis on SPAS and *ATOS*.
3. Develop a DSS survey questionnaire.

4. Interview AFS management, FSDO, CSET, CMO, CMT, principal, and inspector personnel.

5. Write a report documenting our findings, issues, conclusions and recommendations regarding the need for an enterprise-wide DSS within AFS and how the organization could benefit from such a system.

6. Provide three (3) case studies outlining how other organizations have implemented DSS.

3. Process

Listed below are activities we undertook to satisfy the goals and objectives of this Study and generate this report.

- Reviewed the current Flight Standards' handbooks to become familiar with AFS's inspection, surveillance, investigation, and oversight activities.

- Wrote a report describing AFS's business processes and their linkages to the *System Safety Approach*.

- Developed a DSS questionnaire that consisted of 26 questions, divided across the following three subcategories:
  - The System Safety Approach & ATOS
  - SPAS Version II and Version III
  - Desirable DSS capabilities

- Interviewed the following members of the Flight Standards organization:
  - AFS 900
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  - POIs, PMIs, DEPMs, and ORAs
  - CMO for one major airline
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  - the SPAS Development Team
  - the SPAS Program Manager

  To encourage a free exchange of information and ideas, survey participants were assured that the survey participants would have anonymity so only summaries of the responses to questionnaires completed during the interview process were prepared, and they can be found in Appendix A.

- Test drove SPAS to gain a familiarity with its functional capabilities and overall system architecture.

- Conducted expansive research as to the current state of DSS Technology. *(The results of that effort are included in this report.)*

- Recommended a conceptual framework for a DSS capability. *(Please see the DSS Research and Recommendations sections for more details.)*

- Generated this report summarizing the study's findings, issues, conclusions, and recommendations.

- Researched the use of decision support systems in aviation and two other vertical industries. To that end, there is a case study located in the appendices regarding an aircraft fleet maintenance management DSS that is being used by Air Canada. The system was developed by Canada's National Research Council. Air Canada was selected as the *beta* test carrier because of the size and relative age of its fleet. *(Please see Case Study #1, in Appendix C, for more details)*

4. Findings and Issues

From interviews conducted with staff and contractor personnel within the AFS organization, the following is a brief list of the major findings and issues we found in the areas of safety and the need for a DSS.

***Findings*:**

- As an organization, AFS is literally awash in safety data. Unfortunately, much of it is duplicate data, which should only be captured once and maintained by a single system. To do otherwise is not only costly but promotes disinformation.

- Not surprisingly, there is complete anarchy in the area of data management. In many instances, in no small measure owing to the finding above, individual departments are creating their own systems and application databases, which only exacerbates data duplication problems cited above.

- Based on feedback received via the interview process, there is very little confidence in the potential efficacy and effectiveness of the *System Safety Approach* as a way of doing the agency's business. In fact, there was almost unanimous agreement among the interviewees that AFS is doing the *right things wrong* in the way it now conducts business. To explain, the following is offered as a sampling of the many reasons why the participants feel as though the *System Safety Approach* and *ATOS* are two planes headed in the wrong direction:

    1. *ATOS*'s data collection techniques are seriously flawed.

    2. The availability of certificate-holder performance data is not timely nor accurate. Moreover, the granularity of available data is questionable.

    3. The absence of a robust data analysis capability makes it extremely difficult to track performance data and cross-correlate it in an effort to identify *cause-and-effect* relationships, which would be used to improve their ability to focus inspection, investigation and additional oversight activities in the most effective manner.

    4. Poor correlation between certification of new certificate-holders and inspections.

    5. A lack of sufficient resources to adequately address SAI and EPI program initiatives as was envisaged at program inception.

    6. Inspector personnel, at all levels, are extremely leery of computerized systems that are suppose to be productivity aids but, most often, have actually had the opposite effect.

- When asked to describe the system features or capabilities that they feel are most important for an enterprise-wide DSS, survey participants responded with very specific criteria, even though, as a group, they remain skeptical about how such system capabilities might ultimately be delivered. That notwithstanding, the DSS functionality that they think is important includes the following six (6) items:

    a. Workload balancing and scheduling capability.

    b. An online analytical processing (OLAP) capability. (They did not, however, specify whether it should be a relational OLAP or multi-dimensional OLAP.)

    c. A modeling capability.

    d. A DSS should also be capable of providing expert system-like responses, i.e., identify a range of viable alternatives, with corresponding assessments of the probability of success for each alternative posed.

    e. A majority of the interviewees (87%) felt that Flight Standards should only pursue DSS suites that offer an enterprise-wide solution.

    f. Again, 87% of the people interviewed felt that CMOs, ORAs, principals, and ASIs would benefit most from a DSS.

Issues:

- Because no data from an EPI are loaded into *ATOS* until it's completed and signed off, an event that could take months, AFS field personnel need access to interim data describing a carrier's performance to-date.

- The physical and meta-data that drive AFS's mission-critical business processes are not under control. With or without the aid of a DSS, timely, accurate data is the foundation of all good business decisions. The lack of proper oversight in this area has allowed an ever-increasing number of synonyms to exist among the databases that are crucial to AFS's business processes and they should be eliminated.

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Field personnel do not feel as though their input is sought when new programs are initiated, and, on the rare occasion when it is sought, it often goes unheeded. If AFS decides to proceed with a DSS development project, we cannot allow that to happen. Field personnel are the knowledge workers that are crucial to the success of any DSS development effort. During most DSS implementations, it is field personnel that populate, and periodically refresh, the knowledge base that drives a DSS's inference engine.

- It is unclear how AFS intends to make use of the *Air Carrier Operations System Model (ACOSM)* or if it would play a role in a DSS implementation.

- Determine where the *ATOS* Continuous Application Development effort is headed and train field personnel on how to use the system.

- Who is the decision support system customer? Until this question is answered, a number of issues will remain unresolved, e.g., DSS content and other system design issues.

- Is the FAA's IT infrastructure prepared to support the deployment and operation of a network and storage intensive, distributed DSS application? Unplanned IT architecture expenditures could be both costly and delay a DSS project.

5. DSS Research

Introduction

When this Study began, the following two definitions of a decision support system were advanced by the Study's sponsor:

> *A DSS may be defined as: a computer information system that provides information in a given domain of application by means of analytical decision models and access to databases, in order to support a decision maker in making decisions effectively in complex and ill-structured (non-programmable) tasks.*[1]

> *The unifying factor in Decision Support Systems is the focus on the human decision maker. An interactive DSS must be well integrated into the decision process of its human user, i.e., the DSS user must be able to integrate the computer aid into his/her own cognitive process (of decision making).*[2]

We are now at the Study's conclusion, and we are convinced that both definitions are correct. There are three essential ingredients that are precursors to successful decision making and to a successful DSS implementation. They are:

1. ***A decision maker* -** only humans can make and implement decisions.

2. ***Good, relevant data (information)* -** it is through information that one is made aware that a problem exists or a decision needs to be made. And it is through accurate information that either the human brain or a computer can begin to consider data and frame potential solutions to a problem.

3. ***A logical problem resolution methodology***.

Bonczek [1] puts forth the notion that problems exist along a continuum that ranges from highly structured to highly unstructured. (Please see Figure 1.)

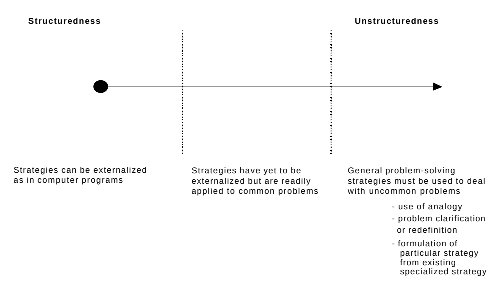

Figure 1. Decision Process

Bonczek, et al.[1], also postulates that there are seven facets of a decision maker. Figure 2 enumerates these seven facets of decision making and depicts the relationships among them. Bonczek, et al., [1] also contend that this portrays an excellent framework for studying and designing computer-based decision support systems.

Based on the diagram in Figure 2, it is clear that decision support systems can only support decisions

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[1] Turban, E. (1988), *Decision Support System and Expert Systems: Managerial Perspectives*, New York: MacMillan Publishing Company.

[2] Zachary, W.W. (1988), *Decision Support Systems: Designing to Extend the Cognitive Limits*, in Handbook of Human-Computer Interaction, ed. M. Helander, London Elsevier Science Publishers.

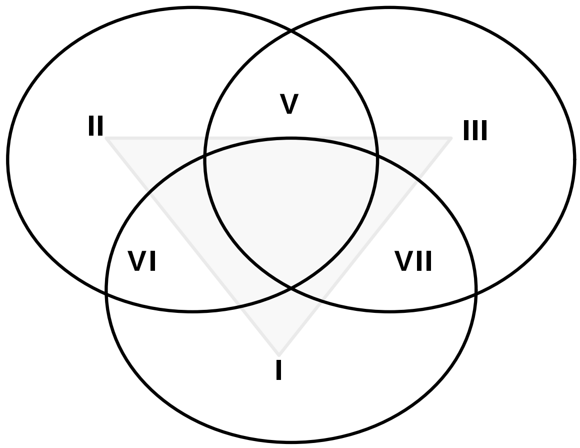

Figure 2. The seven facets of decision making. There are three (3) aspects of decision making (I, power; directive force. II, perspective; information collection. III, design; formulation of models) and four (4) attributes (IV, adaptation; continuous adjustment among the six other facets of decision making. V, analysis; continuing adjustment to perception, reality, and the process model. VI, idealism; continuing adjustment between power and perception. VII, implementation; continuing adjustment between plan and power). (1. Bonczek et. al.)

because they are incapable of demonstrating some of the facets Bonczek, et al[1]., postulated. For example, a DSS cannot make policy, it cannot offer subjective opinions, and it has no intrinsic power. So, while a DSS may be capable of emulating some human cognitive abilities, the system's user must provide those abilities that the system surely lacks.

Figure 3 provides a conceptual model of how man and machine collaborate to enhance the quality of decisions emanating from the decision making process.

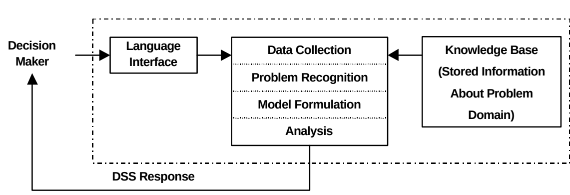

Figure 3. DSS Conceptual Framework

Information Technology vs. Decision Making

Sol, et al. [11] argue there is an ever-expanding body of evidence which suggests that the effectiveness of workers in information-intensive organizations can be improved, but not by just providing more information or more powerful computers. Rather, it is only through more time spent performing in-depth analysis *(cognitive task analysis)* of the tasks that are to be performed. Over the course of the past four decades, analysis of decision making vis-a-vis information processing tasks has been the focus of a great deal of research. But the problem of how to successfully integrate machines (computers) with human cognitive decision processes still eludes us. Why is that?

Many would say that recent information technology (IT), both hardware and software, advancements and improved database management techniques, which affords almost limitless access to data, should lead the way to better, if not optimal, decision making. This view is certainly bolstered by the tremendous advances that have occurred in the area of transaction-based business systems. Systems such as order entry, payroll, accounting and customer relationship management *(CRM)*, which all fall into the same general category of OLTP systems, represent event (static or snapshot) reporting, where as DSS computing is more like a motion picture, both historical and futuristic, at the same time. The progress that these types of systems have made over the last ten years is just short of astounding. But progress on the decision support side of computer automation has not been as earth-shattering because it requires a very different paradigm.

Sol, et al. [11] explains this phenomena by way of an analogy. According to Sol, et al., IT professionals focused on areas that were rich in information (*translation, event-based data*) amenable to computerization in much the same way miners focus on the richest veins of ore: payroll administration or accounting type systems were the mother-load, pure gold. But the types of applications that require a DSS-like computer capability are like mining for mixed grade ore, its hard work. However, a more recent development, which is currently being hotly pursued in the IT and user communities, is data warehousing.

Data Warehousing & Data Management

"A Data Warehouse is a repository of integrated information, available for queries and analysis. Data and information are extracted from heterogeneous sources as they are generated....This makes it much easier and more efficient to run queries over data that originally came from different sources."

Author Unknown

Better data quality and timely delivery of information to those that need it is at the heart of the business demand for data warehousing solutions. Being able to run a business more effectively and gain competitive advantage, from this information, puts this sort of project high on the priority list of any organization. A data warehouse strategy is key to being able to migrate end-user decision support and executive information systems to the desktop. Without such a strategy, business users cannot take advantage of new client/server end-user tools and scalable-parallel database servers to access and analyze corporate data that has become scattered across the enterprise.

To build a data warehouse is, however, a difficult undertaking and needs careful planning of the three areas: business; technology; implementation. When different information (data) sources have to be integrated and accessed automatically, the available and proper use of meta-knowledge (meta-data) concerning the different sources is essential. [7]

Data Warehouse Architecture

The rush is on to build data warehouses. At no time has so much data found itself en route to decision support databases as is the case now. And the trend is only accelerating. As decision support systems become a key strategic direction for many organizations, data warehousing is becoming a commonplace activity.

Early warehousing and data mining efforts followed a very simple (and impractical for the long term) pattern of thought which viewed the warehousing of data along the same lines as the warehousing of physical items. The simple three step process was:

1. Benchmark and buy the hardware.
2. Select a suitable database product.
3. Dump the data into the warehouse.

This paradigm is the mental equivalent of viewing data warehousing as mostly a “data dumping” effort rather than an “information preparation” process. It views a warehouse as cold storage to data for access whenever needed, not as an active laboratory for dynamically analyzing and understanding a business and its customers. Large scale data warehousing needs a different paradigm then the: “Throw it in there and see what happens later” approach — a similar mind-set prevails in the context of toxic waste dumps.

The better approach is a “sandwich” or “bun” paradigm. The “data dump” paradigm is really a “two step” linear process which conveniently (in the short term) separates the decision-support (i.e, data analysis and understanding) effort from the data warehousing effort. In this paradigm, one simply throws all the data into the warehouse first, then looks at it and tries to understand it “after the fact.” With the data dump paradigm, after the data is warehoused, problems begin to surface, however, while attempting to mine the data, because the data was never really understood. The solution provided by the “sandwich” paradigm is quite logical, namely we should try first to understand the data before we warehouse it. Then we analyze it in depth.

In order to mine data, then warehouse data, and finally mine warehoused data will require the creation of a concentric design, which is essentially developing horizontal and vertical prototypes of data before you warehouse it. Thus ensuring that the relationships between and among the datums produced by the prototypes can be established before the data is warehoused. *(Please see Figure 4.)*

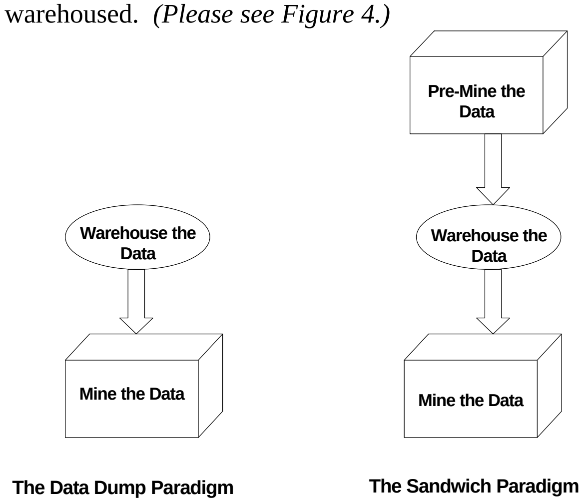

Figure 4.

Data warehousing and data mining can drastically reduce the number of “ad-hoc” reports that IT staff would have to produce and, as a consequence, make that staff available for other important assignments.

One of the key goals of building a data warehouse is the reduction, possibly the elimination, of reliance upon intermediaries for information access. The system allows end-users to walk up to a PC and click on a few icons to perform queries, obtain graphs and reports without talking to a programmer. The ability to access powerful, but simple to use, tools to analyze data is what the end-users see and use. A Data Warehouse should greatly impact end-users’ ability to complete data-driven work assignments, while at the same time creating a positive feeling regarding the entire experience from interacting with the system.

Typically, a data warehouse has three distinct groups of users, supported by programmers and database administrators from IT Staff or a DSS analyst, as depicted in Figure 5.

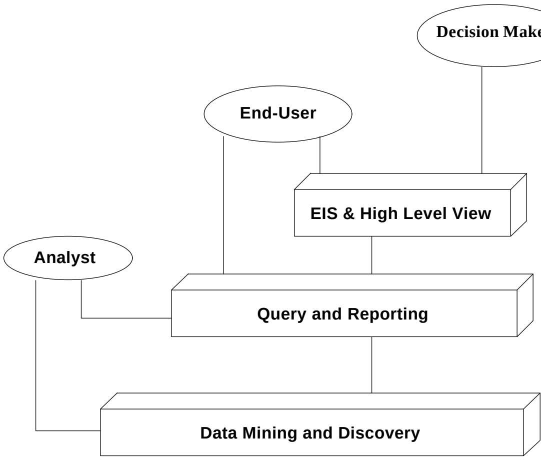

Figure 5. Typical Data Warehouse Users

Current State of DSS Technology

Types of DSS Technology

The following is a matrix of the generic types of decision support systems available in the marketplace today. The matrix's elements are the types of DSS systems, i.e., the underpinning technological approach, and their areas of application [8].

Types of DSS Technology	Application Areas
Data Driven DSS Strengths: Access and manipulation of large databases, OLAP	File drawer and management reporting systems, data warehousing and analysis systems, Executive Information Systems (EIS) executive support systems (ESS). Business Intelligence.
Model Driven Strengths: simulation and optimization models, "What If" iterations. Some OLAP packages have modeling capabilities. Other than OLAPs , which use stored SQL procedures, This type DSS requires user input.	Accounting and financial "what if," " trial and error" iterations. Good for solving common business and manufacturing type problems: scheduling, time series analysis or calculations, dealing with spatial oriented problems, and performing economic impact analysis based on formulas and user input.
Knowledge Driven Strengths: Possesses a domain knowledge base and inference engine. Modeling capabilities and natural language dialogue interface with users. Some have the ability to learn and develop independent data queries within its knowledge domain. Some are hyper-media enabled.	Expert System for specific knowledge domains, i.e., task or industry specific. Also capable of performing application functions that a Model Driven DSS can process. These systems have the facility to deal with problems that contain some degree of ambiguity. High degree of utility when alternatives are sought as part of the decision making process.
Document Driven Strengths: Hyper-media information retrieval capability. Workflow procedure that masks coding conventions that allow substantial to be accomplished non-IT staff	Information (document) retrieval system. Electronic forms and procedure automation. Collaboration through groupware facilities, e.g., virtual electronic meetings, joint document development, control geographically dispersed projects teams.
Communication Driven	N/A
General Purpose	N/A

OLAP and Data Mining

The following are a few terms regarding OLAP servers that are crucial to understanding data warehousing, DSS, and ESS (executive support system, not to be confused with expert system shell)offerings as they are materializing the marketplace.

OLAP is a relatively new technology, and the fact that there are several varieties can be even more confusing. (Han and Kamber's "Data Mining: Concepts and Techniques", Morgan Kaufman)

What is an OLAP Server?

Logically, OLAP servers present business users with multi-dimensional data from data warehouses or data marts, without concerns regarding how or where the data are stored. However, the physical architecture and implementation of OLAP servers must consider data storage issues. Implementation of a warehouse server for OLAP processing may include the following:

- **Relational OLAP (ROLAP) servers:** These are the intermediate servers that stand in between a relational back-end server and client front-end tools. They use a relational or extended-relational DBMS to store and manage warehouse data, and OLAP middleware to support missing pieces. ROLAP servers include optimization for each DBMS back end, implementation of aggregation navigation logic, and additional tools and services. ROLAP technology tends to have greater scalability than MOLAP technology. The Micro-strategy's DSS server and Informix's Meta-cube, for example, adopt the ROLAP approach.

- **Multi-dimensional OLAP (MOLAP) servers:** These servers support multi-dimensional views of data through array-based multi-dimensional storage engines. They map multi-dimensional views directly to data cube array structures. For example, Essbase from Hyperion is a MOLAP server. The advantage of using a data cube is that it allows fast indexing to pre-computed, summarized data. Notice that with multi-dimensional data stores, the storage utilization may be low if the data set is sparse. In such cases, sparse matrix compression techniques should be explored.

  Many MOLAP servers adopt a two-level storage representation to handle sparse and dense data sets: the dense sub-cubes are identified and stored as array structures, while the sparse sub-cubes employ compression technology for efficient storage utilization.

- **Hybrid OLAP (HOLAP) servers:** The hybrid OLAP approach combines ROLAP and MOLAP technology, thus deriving the benefit of ROLAP's more scalable architecture and the faster computation of MOLAP. For example, an HOLAP server may allow large volumes of detail data to be stored in a relational database, while data aggregations are kept in a separate MOLAP store.

Data Management

While there are many sub-topics under the heading of data management, the scope of this discussion will be confined to the relative importance of data management vis-a-vis decision support systems, and the preliminary data cleansing activities that must accompany a DSS implementation effort.

As previously stated, data is one of the three critical prerequisites for a successful DSS implementation. And in that regard, the aggregation and consolidation of an organization's databases into an effective knowledge base is a difficult and challenging assignment. In fact, Michalski, et al [7] write, typical modern information systems process an abundance of data available from many sources, but metaknowledge about that data is usually either not available at all or not available in an easily discernible form. Enormous amounts of low level data must somehow be aggregated to obtain meaningful insights. This task entails creating a reproducible model that facilitates the aggregation and dis-aggregation of existing data to create new data, validate existing data, or correct data inconsistencies between different sources of same or similar data.

This integration of heterogeneous databases, as part of a data consolidation effort, is fraught with problems. Again, according to Michalski, et al. [7] major technical problems result from different database structures, conceptual schemas, query languages, and network protocols. However, the most difficultly is not technical in nature, it is the resolution of data conflicts, which is predominantly a semantics problem.

Whenever two or more legacy databases are consolidated, there will be data entity conflicts. The circumstances that could cause such conflicts to occur are the

1. Schema-Level Relationship Conflicts
   a. Physical Schema
   b. Logical Schema
   c. Conceptual Schema

   For each of the above instantiations there could be one or more of the following conflicts

   1. Entity vs. Entity Relationship Conflict
   2. Attribute vs. Attribute Relationship Conflict
   3. Entity vs. Attributes,
   4. Different representations for the same data

Lim, et al. [6] have developed a typology and proprietary software to categorize and resolve database conflicts.

(RICOMM also offers similar software as part of its I.V.V. and Y2K software suites.) However, the typology developed by Lim, et al. [6] is as follows:

1. Naming Conflicts - Synonyms & Homonyms
2. Structural Conflicts
3. Identifier Conflicts - Bad or improperly constructed Key
4. Cardinality Conflict
5. Domain Conflict,
6. Instance Conflict - Occurs when imported/exported data instances do not relate to each other in a consistent manner

SPAS as a DSS Delivery Platform

The reason SPAS is a part of this report is because the Study required us to render an objective, informed judgement regarding SPAS (i.e., Version III) as a potential delivery platform for a DSS. To that end, the following observations are offered.

SPAS is a web-based, three (3) tier application architecture that performs three critical functions:

A. SPAS is the central repository for AFS's consolidated, safety-related data, e.g., Performance Measures and Performance Indicators.

B. SPAS is a portal to more than 25 active databases, which contain additional raw safety and other data, for more than 3,000 registered users within AFS.

C. SPAS provides a robust, flexible, interactive reporting tool for its users to view standard reports or to develop custom data queries, as the need may arise. SPAS II has in excess of 200 system features.

Although the SPAS client looks and feels like a recently developed system, the back-end of the system is a transaction-based, third generation system. So, from a practical standpoint , converting SPAS into the type of enterprise-wide DSS capability that's needed would be analogous to placing a new blanket on an old horse and telling everyone it's a new horse.

The shortest, least expensive, and least disruptive course of action is to proceed with the DSS requirements study and procure a decision support system that was designed at the outset for that very purpose.

6. Conclusions

- ATOS performance measures (PM) and performance indicators (PI) are flawed because each PM or PI represents observed behavior, rather than a computed value. This means that a PM or PI has very little utility or assistance in predicting future performance.

- In general, there is a serious problem controlling data in AFS. No one is responsible for developing the meta-data that describes the meaning of each data element, which is one of the early and important tasks a DSS development project would require. No one is responsible for maintaining an enterprise-wide, data model and entity relationship model/map for the organization. As previously stated, today, "anarchy" is the word that best describes how data is administered within the organization. However, without immediate attention, the stable will only get messier. Somebody has to take control, now

- Not unexpectedly, the database synonym problem is also fueling the field's displeasure with some of the current computer systems. For instance, if an Ops Inspector wants to add a new aircraft type to the fleet of aircraft operated by a carrier, he or she must input the same information into three (3) different databases (i.e., Operations Specification Subsystem, Vital Information System and Program Tracking and Reporting System) using three (3) different coding conventions.

- Something must be done to forge better relationships among the line functions (i.e., inspectors, principals, CSETs, CMOs and CMTs) and people that are responsible for defining and delivering new system capabilities. At this juncture, field personnel view any new productivity aid or computer system that may be touted to them with a healthy degree of skepticism.

- Before a DSS is implemented, all databases' physical and logical schemas, entity-relationship, and instance-relationship conflicts must be resolved. Just as important is the creation of a data dictionary to store meta-data, which is information about the structure and meaning of data. A fundamental requirement of a DSS (human or cybernetic) is unambiguous, quality, well-ordered data. Without good data, a DSS is useless and good decision cannot be made.

- A DSS could establish a discipline and impose a standard methodology for administering the *System Safety Approach* across all geographic regions, which is something that does not happen today.

- In addition to the CMOs, CMTs, principals, and inspectors, AFS management could benefit from a DSS. Today, when AFS management is asked to respond to Congressional inquiries, a firestorm of data gathering activities ensue, and, at the end of the day, the answer(s) may or may not be correct because the compiled data may not be accurate. A DSS would at least ensure that good data exists and that its method of collection and aggregation are consistently executed across the organization.

7. Recommendations

The recommendations are as follows:

1. Centralize the control of all mission-critical databases under the control of one division. Give that division the authority to cleanup every mission-critical databases' schema, entity, attribute, or instance relationships conflicts. This will eliminate all the problems that synonyms or homonyms may be causing today. (Please see Figure 9, The Semantic Data Model, which outlines an approach that could force database reconciliation but not disrupt day-to-day business.)

2. Begin to build a data dictionary that contains meta-data, which will help describe the meaning of the organization's data. (Again, please refer to Figure 9, in the Illustrations Section.)

3. Consider delaying the implementation of a DSS, particularly in light of the organization's data problems. Good, clean data are necessary prerequisites for decision making and a DSS. However, one way to gain some immediate dividends from the investment of time and money that would be spent fixing database problems is to implement a data warehouse.

4. Study the organization's decision-making processes and determine if they are appropriate or if changes should be made. A DSS should be acquired or built that complements the organization's personality, and decision-making goals and process(es).

5. Prepare and conduct team-building workshops to help foster a better and more trusting relationships between those who merely see themselves as being systems users and those who are systems providers. Much work must be done to re-establish a bond between these two groups, which has eroded over the past several years.

6. Develop a 3 to 5 year, objectives-based, IT strategic plan that's aligned with AFS's business plan. No more missionary work! Take the view that if the customer, which is the operator of the business, isn't ready to execute an element of the plan, move on to the next objective where a customer is ready. (Please see Figure 7, in Appendix D, for more details.)

7. Whether the agency decides to move forward with either a DSS or data warehouse project, the following actions will substantially improve either project's chances for success.

   A. Establish a program office to manage user and development team expectations and project deliverables. Hire an outside firm, as program managers, because they will be more inclined to push for schedule results, without being overly concerned about threatening people's comfort zones in order to move a project briskly along to achieve a project's goals.

   B. Create an AFS internal newsletter. Use the letter as a forum to discuss project goals, objectives, progress, and issues of mutual interest with all project participants or other concerned users.

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APPENDIX A - Interview Results (Summarized)

A Summary of the Study's Interview Results

Questions **Responses**

- **Is the System Safety Approach causing AFS to do:**
  – the right things right? **0**
  – the right things wrong **8**
  – the wrong things? **1**

- **What changes would you make?**
  – Redesign ATOS! **3**
  – Dedicated management commitment **1**

- **Is the System Safety Approach consistently administered within an FSDO and throughout AFS?**
  – Yes **0**
  – No **3**
  – No Opinion **5**

- **How would you improve the System Safety Approach and/or ATOS?**
  – Data capture and collection techniques **3**
  – Improve the correlation between certifications and inspections **3**
  – Data identification **1**
  – Improve the data analysis capability **1**
  – Improve the timeliness of available data **4**

- **Does ATOS capture Performance Measures and Performance Indicators?**
  – No **3**
  – Yes **0**
  – No Opinion **16**

- **Will the System Safety Approach exacerbate the need for sophisticated data analysis and decision-making tools?**
  – Yes **4**
  – No **0**
  – No Opinion **15**

- **Is ACOSM essential to the successful implementation of ATOS?**
  – Yes **5**
  – No **0**
  – No Opinion **14**

- **Do you use SPAS**:
  – Frequently **3**
  – Infrequently **8**
  – Not at all **8**

- **How do you use SPAS?**
  – Data inquiry and reporting tool **4**
  – Workload scheduler **0**

- **Is SPAS a useful tool?**
  – Yes **10**
  – No **0**
  – No Opinion **9**

A Summary of the Study's Interview Results

Questions **Responses**

- **Is SPAS the right platform for a DSS capability?**
  - Yes **8**
  - No **2**
  - No Opinion **9**

- **Should the DSS be an Expert System?**
  - Yes **9**
  - No **1**
  - No Opinion **5**

- **Should the DSS perform workload scheduling?**
  - Yes **10**
  - No **1**

- **Should the DSS provide a modeling capability?**
  - Yes **7**
  - No **1**

- **Should the DSS contain an OLAP capability?**
  - Yes **9**
  - No **1**

- **Should the DSS formulate alternative solutions to a problem set?**
  - Yes **5**
  - No **1**

- **Should the DSS provide economic-impact assessments for recommended alternatives?**
  - Yes **3**
  - No **1**

- **Should the DSS be a:**
  - Enterprise-wide solution **12**
  - A separate system for each category of user **2**

- Which user would benefit the most from a DSS?
  - CMOs **5**
  - ORAs **5**
  - Principals **7**
  - ASIs **1**
  - All of the above **2**

APPENDIX B - The Questionnaire

AVIATION FLIGHT STANDARDS
DECISION SUPPORT SYSTEM REQUIREMENTS QUESTIONNAIRE

***System Safety Approach*:**

1. Based on your understanding of the *System Safety Approach* and the paradigm shift that it brought about in AFS's business processes, would you characterize those changes in business processes and systems as: doing the *right things right*; doing the *right things wrong*, or doing the *wrong things*?

2. If you think the wrong things are being done, what changes would you make, and how would you propose to implement such changes?

3. Regardless of your view about whether the right things are being done, do you believe that the *ATOS* is consistently administered across certificated entities within a FSDO, or across all districts.

4. If you answered the above question no, in general, what recommendations would you make to strengthen the *System Safety Approach* and what *ATOS* specific recommendations would you make?

5. Does the *ATOS* database capture performance measures and indicators, in sufficient detail, to allow AFS surveillance and inspector personnel to accurately assess the operational status and overall safety performance of certificated entities it regulates?

6. Do you agree with the following statement, "the *System Safety Approach* will cause substantial growth in the volume of data collected for performance measures and performance indicators, and that growth will exacerbate the need for better data analysis and decision-making tools"?

7. Do you agree that a completed *Air Carrier Operation System Model (ACOSM)* is an essential element to the successful implementation of the *ATOS* program?

8. If you disagree about how closely linked the successful implementation of the ACOSM is to achieving the goals of the *ATOS* program, what is your alternative strategy for implementing the *ATOS* program and achieving the program's operational goal(s)?

SAFETY PERFORMANCE ANALYSIS SYSTEM (SPAS) UTILIZATION:

9. Are you a casual, semi-frequent, or frequent user of the SPAS database and/or information portals?

10. How would you describe your use of the SPAS database and information portals as a reporting tool, a workload scheduling enabler, a tickler file for follow-ups on regulated entities, a data inquiry tool, or are you a nonuser of the SPAS database?

11. Given the purpose(s) for which you use SPAS, do you find SPAS a useful tool?

12. Does SPAS's database and information portals provide adequate access to America's aviation safety performance data that are both accurate and timely?

13. Are you aware that there is a variance in the effective-use dates between and among the various data records that comprise the SPAS database?

14. Do you think decisions that are based on improperly aged (dated) and/or aggregated (joined) data are invalid? If not, how would you compensate for a decision support system that may fail to age data elements or inappropriately aggregates unrelated data for use in decision-making?

15. Do you think SPAS is the right platform to deliver a decision support system capability?

AVIATION FLIGHT STANDARDS
DECISION SUPPORT SYSTEM REQUIREMENTS QUESTIONNAIRE

16. Would you agree that the project dimensions for assessing SPAS are: goals; information model; technology; results; value? (The project dimensions will be used to determine whether Version III of the system is a success, after it is implemented.)

DECISION SUPPORT SYSTEM CAPABILITIES:

17. Should the decision support system be an Expert System?

18. Should the decision support system perform workload balancing and scheduling?

19. Should the decision support system provide a modeling capability?

20. Should the decision support system be capable of performing independent On-line Analytical Processing (OLAP) of safety data to identify new or emerging data/performance indicators or measures?

21. Should the decision support system formulate alternative solutions to problems? This would include hazard identification, risk assessment, and risk mitigation.

22. If the decision support system identifies solutions or alternative solutions to problems, should the system also quantify the relative magnitude of the economic cost of each identified solution?

23. As a user of the system, what are the system features or functions that would make the system most helpful to you, and why?

24. Should there be one enterprise-wide decision support system or should there be a separate system for each of the categories of users? Please explain the underpinning reasons for your answer.

25. Which user categories do you believe would benefit most from a decision support system?

26. What are the major impediments to developing and implementing a decision support system capability within AFS?

APPENDIX C - CASE STUDIES

CASE STUDY #1 – An Aviation DSS Project

Integrated Diagnostic System (IDS) for Aircraft Fleet Maintenance

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Abstract

The aim of the Integrated Diagnostic System (IDS) project is to research, develop and test advanced diagnostic and *decision support tools* for maintenance of complex machinery. This paper provides an overview of the hybrid reasoning conducted within this system with particular reference to Case-Based Reasoning (CBR) and its integration in this environment. The technical development of this system is outlined as well as an operational review of the field prototype. Furthermore, the development of a distributed, generic architecture for this system to aid its potential widespread implementation is introduced.

Introduction

The Integrated Diagnostic System (IDS) Prototype, Version 2.11 is an applied AI system used to diagnose problems and help manage repair processes of commercial aircraft fleets. For more information on the motivations for, and methodology followed in this project, as well as technical issues covered in the development of this version of the prototype (see Wylie et al. 1997).

Briefly, IDS refines an asynchronous stream of messages consisting of symptoms and repair actions into descriptions of complete fault-repair episodes. The process exploits many knowledge sources, some allowing messages to aggregate, others allowing messages (or messages clusters) to merge, be modified or discarded. The ideal result is clear, concise, complete descriptions of fault events, which unambiguously associate symptoms with appropriate repair actions (Wylie et al. 1997). IDS was built using ART*Enterprise® (A*E), Version 2.0 and makes extensive use of its rule-based and Case-Based Reasoning (CBR) facilities in order to apply various sources of knowledge (manuals, heuristic, historical data) to this problem.

IDS - Operating Principles

The system starts by cleaning up and classifying (using CBR) the message stream from the aircraft to produce IDS Message Objects (IMOs).

These IMOs are then clustered into Fault Event Objects (FEOs). This clustering is conducted using heuristics gathered from engineers and maintenance technicians.

FEOs take input from the Troubleshooting Manual (TSM) objects and Minimum Equipment List (MEL) objects. The TSM objects represent clusters of IMOs, which are identified in the TSM as indicative of particular faults. Similarly, the MEL objects represent clusters of IMOs, which are identified in the MEL manual as indicating that for safety, the operation of the aircraft is restricted in some way.

These symptoms (i.e. message clusters in the FEOs) are then associated with appropriate repair actions. This process, exploits both rule based and case-based reasoning. The resulting Snag[3] Rectification Object (SRO) is then stored.

In the final stage of the process, suggested repair actions are composed and presented to the user. These are derived from historical maintenance events appearing similar to a current FEO (using CBR) and from the Troubleshooting Manual (if the FEO contains a TSM object).

Case-Based Reasoning within IDS

There are two CBR components within IDS v2.11 (Figure 1.0), firstly CBR facilities the retrieval of relevant knowledge from bodies of noisy, poorly structured and incomplete historical information. Secondly, it is being used in the creation of a corporate memory (Leake 1996) of diagnostic repair information for use within IDS and Air Canada.

(See Figure CS-1. IDS V2.11 Data Flow Diagram)

Case-Bases for Message Classification

The Airbus A320 aircraft onboard diagnostic routines generate two types of messages, namely failures (FLR) and warnings (WRN) messages. In total there are about 3400 FLR and 560 WRN cases representing these messages. Messages consist of text and an ATA number; these describe the aircraft components in a hierarchical manner. Messages received from the aircraft cannot be recognized using simply

[3] A snag is a commonly used aviation term for an equipment "problem".

string matching as they may be distorted during transmission. To overcome this, two case-bases have been created for all the FLR and WRN messages. As messages are received the strings and ATA values are matched using trigram matching against the appropriate case-base and associate a unique identifier with the message object that is created. A threshold for matching allows poor matches to be flagged. Occasionally, messages are received that are not in the case-base; these are investigated to see if this is a valid message that needs to be added to the case base.

ART*Enterprise® CBR tools are being used here to provide the low-level inexact matching best described as an unusual, implementation of an episodic memory and one where it is difficult to justify the use of the acronym "CBR" (Wylie 1998), (Watson 1997). While the use of a case-base to identify messages and assign unique identifiers is not a standard use of CBR, this implementation has proven to be robust in matching messages.

Case-Base for Diagnostic Experience

This case-base is usable as a corporate memory allowing retrieval of historical situations, which appear similar to the current situation, providing a means by which maintenance technical experts can feed their knowledge back into line maintenance system.

Presently, the case-base is managed through an off-line facility (the Snag Case Management Tool). This application allows the user to browse the SRO database, clean up the contents of an SRO, convert SROs into cases, test a new case against the existing case-base (for redundancy and consistency) and add it to the case-base.

On-line, the snag case-base is searched each time a FEO is selected by the user. If a case is found which has similar symptoms (clusters of IMOs) then it is retrieved. From the retrieved cases, repair actions are extracted and used to suggest courses of action to the user. The tight integration of this type of CBR mechanism into a large hybrid reasoning system, makes IDS interesting. At the moment, effort is focused on precisely what diagnostic role the Snag case-base should be playing in IDS, for example should it be refining diagnoses made using TSM knowledge or should it be catching faults missed by the TSM. In addition, how should the CBR system work from an organizational perspective with respect to case creation and validation policies (Kitano and Shimazu 1996) and what impact does the CBR system have on communications between the technical maintenance staff and the line maintenance staff?

Evaluation of IDS

The IDS v2.11 prototype has been on extended field trials at Air Canada for 9 months. This has led to considerable use of the prototype and generated valuable feedback. During this time the prototype development has been reviewed to assess the execution of IDS v2.11 and highlighting future research issues (Dubé & Wylie 1997). Technically, IDS v2.11 demonstrated that hybrid AI reasoning systems are practical and can be built using currently available tools, but development can require a degree of customization to achieve acceptable results. The use of appropriate tools is critical in building such applied AI systems. A*E reduced the effort involved in the development of IDS but because of time constraints, asynchronous nature of the system, it is not a typical application of A*E, this stretched the envelope of the development environment.

The development of IDS has confirmed the belief that to be useful as a decision making tool. To be useful, systems must be closely coupled to the organization's underlying information flows. A corollary to this is that development tools must provide good data integration to existing applications.

Meanwhile, feedback from Air Canada has indicated that an "intelligent" application the automatically collects, groups and assesses sets of fault symptoms and automatically alerts maintenance personnel is an asset. The ability to automatically refer the user to the pertinent maintenance manual pages to support the fault resolution process is also extremely useful.

Overall, recommendations were for a system incorporating more intelligence and one that integrated with most of the information systems related to the maintenance operation. This is one of the goals of IDS-98.

IDS-98: A Distributed, Generic Maintenance Management System

The goal of IDS-98 is to create a new version of the IDS software, which builds in an "evolutionary way" (McConnell 1996) on the functionality of IDS v2.11, but has a distributed architecture and reflects a generic maintenance management system that could be applied to other application fields. In addition, IDS-98 will constitute a flexible infrastructure for integrated reasoning research including "operationalizing" (use) of structured technical documents, CBR and data mining (Wylie 1998).

Initial attempts at distributing IDS v2.11 involved duplicating the asynchronous message feeds as well as the entire IDS application for each instance of the application. This meant that each IDS application did the same inferencing and database manipulation, this was not an ideal solution for a system that will potentially be installed across Air Canada's maintenance operations. To overcome this, IDS-98 has a distributed architecture making use of ActiveWeb® a Message-Oriented Middleware (MOM) product from Active Systems. MOM refers to the process of distributing data and control through the exchange of messages (Orchard 1997). ActiveWeb does this by defining a standard unit for capturing and exchanging information called an "event". At the heart of the ActiveWeb system is a "broker" which handles the distribution of events. The new architecture of IDS-98 presently consists of an IDS v2.11 application connected via a Java® interface to an ActiveWeb broker. Messages from the aircraft are sent to the IDS application where the inference is conducted and then the resulting information is distributed to lightweight remote Java applications. This work is currently in development, but the goal of IDS–98 is to adopt this architecture, to which other modules of the IDS-98 system will publish and subscribe to the extant events.

New Modules in IDS-98

The basic functionality of IDS-98 will build on IDS v2.11 but will include several additions, integration of multiple reasoning techniques, mobile implementation, extend to other fleets, additional CBR functionality and a data mining and trending module (Létourneau, Matwin and Famili 1998). From a CBR perspective the main focus will be the enhancement of CBR functionality. This work will initially focus on the two aspects of the current tool, firstly user requirements and a task analysis exercise, and secondly case attribute definition and representation. The re-evaluation of the case attributes is in response to suggestions from Air Canada that a richer set of attributes may be needed for case representation. This is a critical area of CBR implementation (Lehane 1997).

In addition, the functionality of the existing case base management tool will be enhanced by providing several additional features. Presently, recurring symptom sets, which lead to the creation of FEOs, are not highlighted, within IDS-98 such FEOs will be highlighted graphically within the case creation tool. This will allow the user to track problems that recur more easily. The second addition will allow case creators to assess the benefit of adding cases to the case base. At the moment, before a case is added to the case-base a user can check for redundancy and consistency. An instrumentation module has been developed which tracks the frequency of case retrieval allowing an assessment of case usefulness. The integration of this module within the case base management tool would allow evaluation of a new case against a historical subset of data to check for instances of retrieval. It is also intended that a version of this instrumentation will run in the background and track the frequency of case retrieval to facilitate evaluation of the case-base. The final development component is the creation of a case-base browser to allow viewing of stored cases.

Conclusions

The development of IDS has demonstrated both the importance and viability of an integrated decision making system for the maintenance of complex fleets such as aircraft. The evolution of IDS from v2.11, through to IDS-98 underlines the intent within the Integrated Reasoning group to continue this development in an evolutionary way adding technical functionality that provides measurable utility and advances the use of integrated hybrid reasoning systems.

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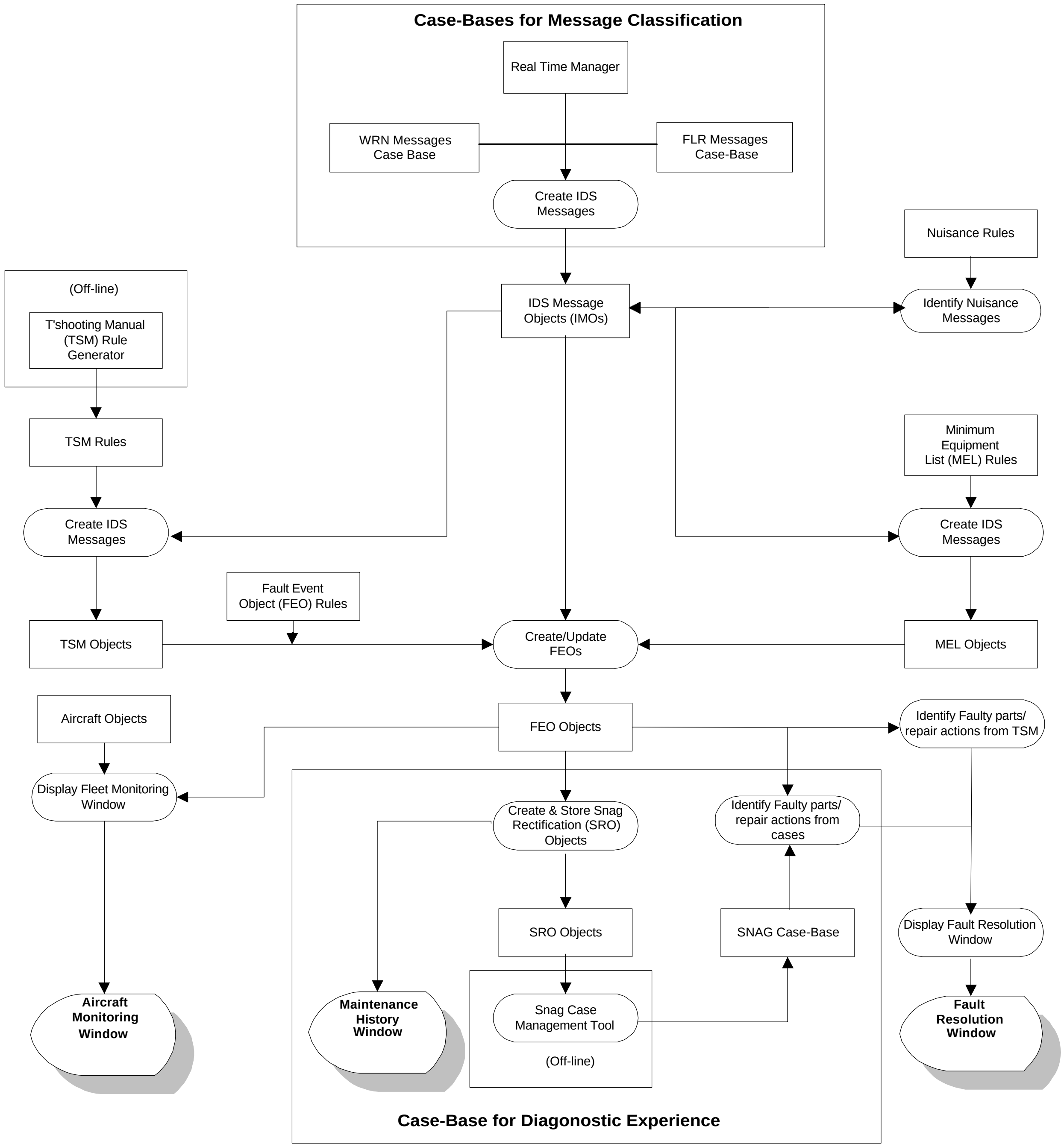

Figure CS-1. IDS V2.11 Data Flow Diagram

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CASE STUDY #2 – A Maintenance Management DSS Project

Decision Support System for Maintenance Management

Introduction

Offshore petroleum production installations are becoming more and more automated, with reduced equipment redundancy as one of the targets for cost reductions. Maintenance is a significant factor in the lifetime profitability of such installations because it causes production downtime and requires resources for maintenance operations.

MARINTEK has, over the last 20 years developed methods, procedures and systems for the shipping and offshore oil and gas industries, with the aim of improving operation and maintenance of the installations. That knowledge and experience are now being used to specify and design a Decision Support System (DSS) for maintenance management.

The increased focus on use of process information has come as a result of the continuous improvements in computing technology and applications, especially with respect to characteristic properties like reliability, user-friendliness and standardization. Today, almost any new offshore installation is equipped with information systems dedicated to process control, condition monitoring, and maintenance and production management.

Integration of Information Sources is Important

Typically, such information systems are run on different computers on-board an offshore platform, and they are used by different people that work in different sections. However, the various systems contain data which are valuable for maintenance planning, and there is, accordingly, considerable potential for improvements and cost savings in combining these data from the various systems.

A fusion of data from such systems into a Decision Support System (DSS) will provide system users with:

1. valuable mission critical data,
2. answers to "what-if" type questions, and,
3. given a set of pre-determined, objective decision criteria, identify alternative maintenance strategies.

DSS - Decision Support System

To be able to access these features requires a system comprised of one or several databases, simulation and/or optimization models, and user interface dialogues. A decision scenario covered by a prototype DSS, which is similar to one currently being developed at MARINTEK.

(*See Figure CS-2 which illustrates the concept of a DSS designed to improve equipment maintenance decision-making, minimize maintenance-related downtime, and reduce the maintenance costs of an offshore installation or plant.)*

Most process control systems have subsystems or equipment connected in series or the system works in tandem with another system(s). When maintenance is needed, either due to a scheduled preventive maintenance task or unscheduled equipment failures, the operator must review the condition of all of the equipment in question. He/she has to decide which equipment to repair and what the critical timing is for each repair action, whether it is planned or unplanned. The DSS prototype assists decision-makers in choosing the most favorable alternative based on costs, benefits and probabilities of failure for each set of alternative repair actions. The analysis is based on a "decision tree" concept with choices - what to repair and when - and chances "which equipment will have a fatal breakdown and lead to an unplanned shut-down of the installation". The decision tree is generated automatically by the DSS, based on the available data.

Prototype Development

The prototype development afforded MARINTEK an opportunity to collaborate with members of Stanford University's Center for Integrated Facility Engineering (CIFE). A visiting researcher from MARINTEK and a visiting professor from the Norwegian University of Science and Technology worked together with the CIFE team for a four months period during the autumn of 1994.

This collaboration is still going on, and MARINTEK is currently using a software library from Stanford's Computer Science Department to support the concept of Agent-Based Software Engineering. The library has been used to set up a framework for connecting different applications which may reside on different computer platforms in a network, and which cooperate transparently without limiting the use of an application to its original system. This is essential to the proposed DSS concept, which offers communication possibilities with, for instance, different condition monitoring systems with a minimum of customization.

The further development of the prototype will make use of ROMEX - a fault diagnosis system for rotating machinery as a feeder of condition data. Two systems for maintenance management are currently being evaluated by MARINTEK for use as a feeder of maintenance and spare parts data.

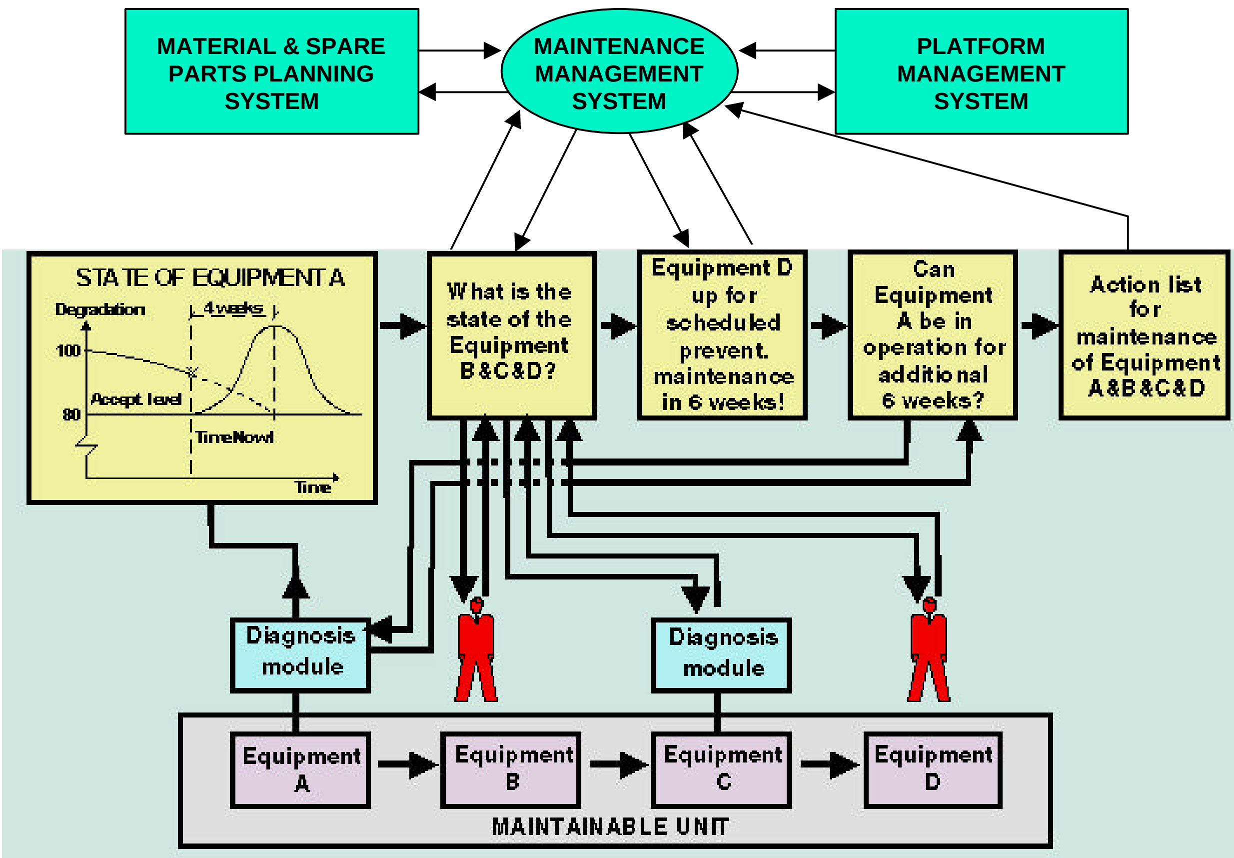

Figure CS-2. Maintenance Management DSS Conceptual Model

CASE STUDY #3 - A Diagnostic DSS by Domain Experts Project

Development of a Diagnostic DSS by Domain Experts

Contact Point

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Executive Summary

The objective of this application experiment was the development and establishment of a decision support system for standard operations in the field of orthopedic surgery, with the aid of an expert system shell (D3) to produce a knowledge-based, patient diagnostic and treatment information system. The communities of interest were clinics and companies that were developing clinical information systems and knowledge-based systems in the medical arena.

The companies involved were Orthopedic University Hospital of Heidelberg (OUHH) and Ibek GmbH, Karlsruhe (Germany), a vendor of an expert system shell (D3).

The hospital began to use information technology in medical areas in 1993. At that time, OUHH was not method in use for knowledge engineering. However, the hospital professional staff possessed exclusive orthopedic knowledge that was only accessible to a few people and it was not well documented.

The methodology used for the project was M4D, which is a management and engineering methodology for the development of decision support systems. It supports the whole software cycle. M4D's approach is based upon the STEPS-Methodology (Software Technology for Evolutionary and Participatory System Development).

The main elements of the project work plan were preparation of the application project, application development, evaluation and implementation activities.

Cycle I of the project produced a prototype of an expert system with 208 symptoms and 1345 rules for 9 medical diagnoses in orthopedic surgery.

The results and experiences of the development phase made it clear that the use of expert systems in orthopedic surgery was not viable, at least the Heidelberg Clinic. This was in large measure due to the complexity of the treatment decision-making processes and as a result of insurmountable information, technical difficulties, very low user acceptance, and difficulties obtaining a commitment for future technical support and further development. That is why the software engineering of the expert system was abandoned after Cycle I of the project. As a result, the hospital decided to concentrate its efforts on developing hypermedia systems.

1.0 Background Information

1.1. Objectives

The objective of the Expert System application experiment of the Orthopedic University Hospital of Heidelberg was the development and establishment of a decision-support-system for standard operations in the field of orthopedic surgery. The decision support system was to support surgeons who have to decide which operative therapy is appropriate for a known diagnosis (consulting model). It is a given fact that explicit guidelines do improve clinical practice (Schoenbaum and Gottlieb 1990). Therefore, it was anticipated that the expert system would improve the quality and efficacy of medical treatment, particularly in elective surgery. The main objective, however, was the integration of a decision-support-system (D3) into a clinical information system, a system that they are now developing.

For the development of the decision support system they used the engineering and management method M4D (Methodology for the Development of Diagnostic Decision-Support-Systems by Domain Experts) and the development tool D3. It was believed that M4D and D3, as high-level software engineering standards, would enable the hospital interns to develop decision support systems and improve the software development process. They expected the project to last for 18 months.

1.2. Involved companies and their roles

OUHH's partner in the project was Ibek GmbH, Karlsruhe (Germany), the vendor of the expert system shell D3 (developed by Puppe et al., Würzburg), and they provided training for the engineering and development method M4D and for D3. Ibek GmbH, Karlsruhe's project role was:

- Preparation for the application project
- Preliminary project planning
- Analysis of pilot application experiences
- Training for project managers: fundamentals of M4D
- Design of the entire evaluation
- Planning of communication actions
- Application Development
- Project planning
- D3 software installment

• Training of knowledge engineers and medical domain experts
• Support of Cycle 1

The role of Orthopedic University Hospital of Heidelberg was:

• Project management
• Development of the prototype of decision support system (D3 for diseases of the knee) and an information system, plus building the interface between these two systems
• Development of a meta-algorithm (data model) for decisions in operative orthopedic surgery
• Development of algorithms for knee operations
• Reporting and communication activities

1.3. Starting scenario

In 1993, the Orthopedic University Hospital of Heidelberg started building up its own software development competence and capacity. Prior to that, the hospital did not use any computers, software or tools for quality management. No computers were being used in the delivery of medical care before 1993, especially in the operating theaters. In 1994 a project called strategic information planning was started together with Ernst &Young using the Case Tool ADW. The James Martin information engineering approach was used as the planning methodology. The key objective was to provide the guidance necessary to explore the business infrastructure and to identify information that managers needed to exercise effective control over the use of information technology.

After an analysis phase, in which they developed a business area information model, they started the Expert System project. The project team consisted of four people. A parallel activity line was the work on notational standardization of medical knowledge for standard operations in the orthopedic field. A feasibility study with a positive outcome using the tool D3 was executed before starting the Expert System Project.

Conclusions from the feasibility study were:

• Long-term project planning and management is necessary for the development of a knowledge-based system.
• An evolutionary product development life cycle model should be used.
• Domain experts should implement the knowledge base themselves.

Technical

At the start of the project there were 20 computer workstations in use at the hospital. They started using 486 machines with color monitors. By the end of 1995, 205 PCs were in use and distributed throughout the hospital - among them two MacIntosh computers. All PCs were connected to a common network.

The hospital has built a network connecting nearly all buildings. Standard protocols are used. The operating system is Windows NT (both servers and clients). A client-server-based architecture was implemented. Four of the ten servers were Compaq-Servers (4500). The applications used graphical user interfaces. The consistency of the user interface across all applications reduced the costs of user training.

Our Department of Information Technology was equipped with twelve computers. They used standard software and tools (ABC-Flowcharter, MS Access 2.0, Word 6.0, MS Project, Corel Draw). ADW as a standard tool is used for Data and Process modeling and as a knowledge base.

Business

The Orthopedic University Hospital Heidelberg is one of the biggest orthopedic clinics in Europe with 320 beds. They cover all specialist branches of orthopedic surgery. The staff consists of more than 1000 persons. More than 7.000 operations are performed each year.

Data processing at the clinic was supported by a central administration system (SAP, R3, ISH) using NT as an operating system platform, which was introduced 1995.

Organizational

The organizational environment in which the project took place was the Department for Information Technology and Quality Management. At the beginning of the project there were four project members: two physicians, one medical documentary and one information scientist. Apart from the feasibility study, the group had no experience with expert systems.

Cultural

Based on experience from a previous study, the hospital recognized that organization and information flow were shortcomings. For instance, the special orthopedic medical knowledge, in particular, knowledge about operations, was scarcely documented and concentrated in the heads of a few experienced people. This situation called for new concepts and information technology tools to manage and make the medical treatment decision processes more transparent, especially for younger colleagues.

Therefore hospital management decided to introduce information technology tools within its medical departments in 1993. Until then, methods and tools for quality management had not been in use. This was especially true in the operating theaters.

Despite these facts, it was fully anticipated that the hospital's physicians would resist any changes in their work environment

Skills

The staff of Ibek GmbH that were involved in the project were experienced with the M4D methodology and knowledge engineering.

The staff from the Department of Information Technology and Quality Management had knowledge about project management and sufficient medical knowledge.

1.4. Work Plan

The main elements of the work plan were as follows:

- Preparation of the application project
- Application development
- Evaluation
- Communication activities

The deliverables were: preliminary project plan, reports on analysis results, M4D Manual, Version 1, Evaluation plan, Project plan, application system version 1, knowledge base documentation, midterm Report, progress report.

1.5. Expected outcomes

The expected results of the project were the development of a decision support system for the preparation of standard operations in orthopedic surgery and improvement of their software development process. The expert system was expected to support the physicians working practice and so improve the quality of their work.

2.0 Work Performed

2.1. Organization

There were four persons involved in the project: three physicians, and one computer scientist.

The Department of Information Technology, Ibek GmbH, and Hospital professional staff participated in the project. The management structure consisted of a project manager, medical experts, a knowledge engineer, users, and a vendor.

2.2. Technical Environment

Before starting this project, the hospital's IT and professional staff had no experience with methodologies for developing decision support systems. However, one of the project's goals was to have the users of the system develop it. The M4D Management methodology for the development of a decision support system was therefore introduced in order to improve the knowledge engineering and software development capabilities of the hospital's staff.

2.3 Training

M4D is a management and engineering methodology for the development of decision support systems, which is based on software development by domain experts. It supports the whole software cycle. M4D follows the STEPS-Methodology (Software Technology for Evolutionary and Participatory System Development).

A specific M4D training course was provided as a part of the project by a consultant from Ibek GmbH. Among the topics covered were risk analysis, risk management, prototyping, design, construction and system evaluation (testing).

Special attention was given to the role of knowledge engineering within the expert system shell D3 (heuristic classification). D3 is an expert shell for heuristic classification. The main object types were symptoms, diagnoses, question sets, suggestions and rules.

2.4. Role of the consultants

The role of the consultant was to support and train the project team.

2.5. Phases of the project

The project had the following phases and three cycles (cycle 2 and cycle 3 were not performed):

Phase 1. Preparation of the application project. This contains five stages:

- Preliminary project planning consists of framework planning, establishing the main project organization and Expert System risk analysis and risk management
- Analysis of pilot application experiences, training for project managers: fundamentals of M4D, socio-technical systems analysis and design, project establishment, user participation,
time/cost estimation and control, and risk management
- Design of entire evaluation (test plan)
- Planning of implementation actions

Phase 2. Application development. This contains five stages:

- Project planning: socio-technical systems analysis, analysis of existing data and knowledge structures, socio-technical systems design, planning of realization, project organization, risk analysis and planning of risk management, project review procedures
- D3 software installation
- Project presentation within the hospital
- Training for knowledge engineer(s) and medical domain experts: review test procedures, use of D3 tool, Knowledge engineering, knowledge base maintenance concepts, documentation, methodical process improvement, methodical method and tool improvement
- Cycle I of the project had six parts.

First, defining version 1 and reviewing version 1, as well as establishing a test plan and a test environment.

Second, System development: Knowledge modeling and implementation

Third, User training: use of application and development of a model for the knowledge domain in question

Fourth, Application system review: testing followed by test evaluation, then formulation of chance recommendations for the application system as well as for D3. Risk monitoring and control actions.

Fifth, process review: it contains formulation of change recommendations for the development method M4D and for the second cycle.

Sixth, The final step of this cycle was to review the Expert System Project. The original project plan called a second and third cycle, which would be based the results obtained in the first cycle, with elements identical to Cycle 1.
However, based on the problems mentioned below, Cycles 2 and 3 were canceled.
In the work plan called for the application project to last for 9 months and the application development, including cycles 1, 2 and 3, to last fifteen months.
Lastly, the evaluation was to last two months.

2.6. Internal communication

A kick off meeting with 8 physicians was held. Training courses for the Tool D3 and the methodology were offered to physicians. The physicians' responses was not very encouraging.
The hospital conducted two workshops over a two year period, May 1994 and May 1995, where the Expert System Project details were presented. Two papers and two posters about the results of the projects were also published. During discussions in the workshops, the main point of criticism expressed was the doubt that it would be possible to integrate the expert system into the hospital's work environment. Usefulness of the system was also questioned.

3.0 Results and Analysis

Within the main work packages 1 and 2.1 - 2.5, Cycle 1 of the development was completed. The results are as follows:

3.1. Technical

The result after Cycle I was a prototype of an expert system with 208 symptoms and 1345 rules for 9 medical diagnoses in orthopedic surgery.
CLASSIKA, as an instrument for knowledge acquisition, provided a good instrument for developers and a good graphical knowledge representation. It facilitates human experts to represent their knowledge graphically by:

- entering domain vocabulary of symptom names and diagnosis names into hierarchies,
- specifying local information to those terms by filling-in forms and
- establishing relations by arranging and filling-in tables or rule forms (Gappa and Poeck 1992)

We were confronted with the following problems:
Using the D3 tool, It was not possible to create an expert system within the time frame. The main reason was that the interface was too complex and therefore too expensive. Users had great difficulty using the D3 tool because they were unaccustomed to the windows-based, graphical user interface. The greatest problem, however, was that the data input into the new system required too much time. Moreover, the input and output techniques were not clearly defined, and they were counter-intuitive. The D3 shell has a relatively inflexible knowledge model (Gappa and Poeck 1992). At certain stages, it became evident that an expert cannot introduce his/her knowledge into an inflexible system in a satisfactory way.

3.2. Business

The results of the project had an indirect impact on the business organization. After Cycle I of the project, it was clear that the documentation of the patients' data, especially the history data concerning examinations and results, should be loaded into a transaction-oriented, computerized information system. After that, the data can be ported or made available to an expert system. The manual inputting of such data by knowledge workers, without self-documenting screen scripts, is not recommended. In this case, the lack of a well designed, intuitive input screens increased the time the physicians needed to input patient data and decreased their ardor for the expert system.
The prototype was eventually finished and received limited use in a special outpatient department. It was their aim to create an interface to the system, which unfortunately they were unable to do.

3.3. Organization

The project results have shown that there were some flaws in our project management approach. The weekly control of the project was not monitored sufficiently enough and the format of the meetings was too informal.
D3 and the acquisition of medical knowledge and the problems thereby encountered, led to two people leaving the project by the end of 1994. Consequently two new project members had to be found and trained. This was viewed as a serious or extreme setback for the project.

3.4. Culture

The project had no positive impact because of the complexity of the expert system and the weakness of the M4D methodology. Instead of lightening the workload, users tended to find the expert system unsettling and difficult to handle, which caused users to develop negative attitudes toward information systems in general.

4.0. Key Lessons

4.1. Technological point of view

Despite the difficulties in knowledge acquisition and in having only a limited opportunity to test the prototype, the results showed that CLASSIKA, as an instrument for knowledge acquisition, is a good tool for developers and a good graphical knowledge representation. It is easy and quick to learn. It would have been helpful to consult with experienced physicians while building the knowledge base. This would have improved the quality of the knowledge base, and it would have helped build a better understanding of the system, while at the same time improving users' general acceptance of the expert system.

Project results have demonstrated that it is possible, in principle, to create an expert system in the field of orthopedic surgery. M4D is a methodology for the evolutionary participating development of expert systems by domain experts. The system is developed in an iterative way.

Contrary to their high expectations for D3, the project team did experience a few problems with the D3 tool. Using probability factors, some diagnosis (e.g. rupture of anterior cruciate ligament) showed that the system is prone to mistakes when new criteria are introduced.

During the project there was a problem caused by D3's interface to RDBMs. The interface was under development at the time of this project was executed.

Understandably, based the experience from this project, OUHH has categorically decided only to work with standard products that are commercially available and widely supported in the marketplace. The D3 system, as developed by Puppe, was not available in the marketplace when they undertook this project, and they had little or no technical support. That was one of the major reasons they decided to stop the project.

Another obstacle was the hardware/software platform restrictions imposed by the expert system shell software. D3 required a Macintosh computer and at the time of project initiation it was not available with a MS-Windows interface. Integrating a Macintosh desktop platform into the hospital's network environment also caused several nagging and resource consuming problems.

4.2. Strengths and weaknesses of the project

One strong point is that the hospital is now in possession of a validated data model of the hospital's knowledge-base which has already been successfully used in other projects. Another goal was to develop a medical expert system within a hospital. It was believed that any development of such a system outside a hospital or medical facility is fraught with problems.

Our Project experience has shown that decision making in orthopedic surgery is extremely complex. Based on the work performed for this project, they discovered that for a decision within orthopedic surgery there are at least 30 main criteria, each with a minimum of 5 parameters to be considered, although there was no published data on this topic. In the project they maintained criteria and published them (Cotta et al. 1995).

As a result of the first cycle, the hospital firmly believes, at least for its special field of endeavor, that due to this complexity it is impossible for an expert system to give good straightforward decisions, particularly, because of the importance of the human element in medicine.

They also experienced difficulties with medical knowledge acquisition, due to the shortage of available time for experts to participate in such a project.

5.0. Conclusions and Future Actions

The defined goals were not fulfilled. The complexity of the decisions for individual patients seems to be too high to be effective when transferred to an expert system. For that reason, the project team concluded that an expert system in orthopedic surgery could not be constructed and be fully functional. The development of an expert system in the required format would be so time-consuming, that more than one team would be needed to have a chance to reach the goal.

An expert system in a hospital that is not integrated with a patient history information system is not useful. **Questionnaires completed by OUHH surgeons showed a lack of willingness on their part to enter the results of medical examinations into an information system and then into an expert system.**

The concurrent development of an information system and an expert system is necessary, as they have to use the same medical vocabulary. At this stage, OUHH feels it is important to stress that before starting this project there was no controlled vocabulary (taxonomy). However, it critical to the success of any DSS project that a vocabulary be constructed and agreed to that will guide the DSS development effort.

The introduction of expert systems in medicine that require a renewed input of already documented data has failed due to acceptance problems. The goal of integration of clinicians in the project failed because they had little time and low interest. Despite the difficulties in knowledge acquisition and in having only a few possibilities for testing, the results have shown that the used forms of knowledge representation and inference mechanisms are suitable for the decision finding.

One has to be careful that no expectations for a quickly created and perfect system are instilled among the customers or users. The construction of the prototype has shown that a DSS will evolve over time.

The documentation of the patients' data, especially the data of examination history and results, should be done in a computerized information system. After that, data can be transmitted into an expert system and not vice versa. The manual input of the necessary data by the user without very rigid editing and data exception routines is not recommended, as the increased need for time and work to accomplish the task will decrease user acceptance of the DSS. The formalized and standardized patients' data investigation should be done before or at the beginning of the project to make sure that enough cases for knowledge acquisition and testing are available.

It is absolutely imperative that practitioners participate as knowledge workers to help build the knowledge-base of a DSS or expert system. In order for a DSS or expert system to be viable, it must be comprehensive, up-to-date, and easy to use, otherwise it will not be accepted. Securing the active participation of experienced practitioners is one sure-fire way to make that happen.

A measurement of project results is not possible because the project was halted. However, it is worth noting, the hospital's physicians gained an awareness of the potential value of computer-based tools, and they now wish to standardize and document their medical treatment regimens, but not using expert systems.

In conclusion, the department of information technology decided to stop all development work on expert systems and to concentrate its future efforts on developing a comprehensive data dictionary (meta data) in orthopedic surgery on the basis of the data model and hyper-media (information) systems. A hyper-media system - according to their preliminary experience- has a better chance of being accepted by the hospital's physicians.

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APPENDIX D - Glossary of DSS and Safety-related Acronyms & Mnemonics

ACAS Air Carrier Analysis System
ACRA Airman Certification Rating Application
ACSEP Aircraft Certification Safety Evaluation Program
ACOSM Air Carrier Operations System Model
AD Airworthiness Directive
ADS Airworthiness Directives Subsystem
AEC Aircraft-Engine Combinations
AES Automated Exemptions Subsystem
AFS Flight Standards Service
ANNs Artificial Neural Networks
APD Aircrew Program Designee
APR Aviation Program Resources
ARC Acquisition Review Committee
AS NTSB Accident System
ASAP Aviation Safety & Accident Prevention
ASHIS Aviation System Hotline Information System
ASI Aviation Safety Inspector
ASRS Aviation Safety Reporting System
ATA Air Transport Association
ATOS Air Transportation Oversight System
ATS Airman Test & Schools System
AUPRS Air Carrier Aircraft Utilization & Propulsion Reliability System
AVR FAA Associate Administrator for Regulation and Certification
BCS Business Credit Service
BBNs Bayesian Belief Networks
BPI Bits Per Inch
BTS Bureau of Traffic Statistics
CA Check Airmen
CAA Civil Aviation Authority
CAIS Comprehensive Airman Information System
CAMS Core Automated Maintenance System
CARA File Civil Aviation Registry's Activity File
CARB Commercial Airlift Review Board
CARC Commercial Airlift Review Committee
CASE Computer Aided Software Engineering, or
CASE Coordinating Agency for Supplier Evaluation
CEO Chief Executive Office
CFI Certified Flight Instructor
CFR Code of Federal Regulations
CLP Constraint Logic Processing
CMT Certificate Management Team
CO DoD Cockpit Evaluations (Data)
COD Concept of Operations Document
CORN Computer Resource Nucleus
CPU Central Processing Unit
CSET Certification, Standardization & Evaluation Team
DA Designated Airmen
DAR Designated Airworthiness Representative
DAT Digital Audio Tape
DBA Database Administrator
DES Data Encryption Standards
DIS Designee Information System
DME Designated Mechanic Examiner
DMS Designee Management System
DoD Department of Defense
DOT Department of Transportation
DPE Designated Pilot Examiner
DPRE Designated Parachute Rigger Examiner
ECD Experian Credit Data
EIS Enforcement Information System
ENV NVIS - Environment
EPI Element Performance Inspection
EPR Enhancement & Problem Report
ESS Executive Support Systems
FAA Federal Aviation Administration
FAR Federal Aviation Regulations
FDD Functional Description Document
FH NVIS - Fleet History
FSDO Flight Standards District Office
FSIS Flight Standards Information System
FTD Flight Training Devices
G021 Air Force Data System Designator for Core Automated Maintenance System for Mobility/Malfunction Detection Analysis and Recording System
G081 Air Force Data System Designator for Product Quality Deficiency Reporting System
GB Gigabyte
GDSS Group Decision Support System
GUI Graphical User Interface
HOLAP Hybrid Online Analytical Processing
HPCL Hewlett-Packard Command Language
Hz Hertz
IA Inspection Authorization
IAIDS Improved Accident Incident Data Subsystem
IAOIS International Aircraft Operator Information System
IBM International Business Machines
ICAO International Civil Aviation Organization
ID Identification
IE Internet Explorer
IPT Integrated Product Team
IRS Interface Requirements Specification
IRT Item Response Theory
ISA Industry Standard Architecture
JAR Joint Applications Requirements
KDP Key Decision Point
KBPS Kilobits Per Second
KPH NVIS - Key Personnel Historical Data
LAN Local Area Network
MB Megabyte
MDP Management Decision Paper
MDS Management Decision System
MDSS Multi-Participant Decision Support System

MEDA	Maintenance Error Decision Aids
MHz	Megahertz
mm	Millimeter
MMEL	Master Minimum Equipment List
MNP	Microcom Networking Protocol
MNS	Mission Needs Statement
MOLAP	Multi-dimensional Online Analytical Processing
N/A	Not Applicable
NAA	National Aviation Authority
NAIMS	National Aviation Information Monitoring System
NARIS	National Aircraft Registry Information System
NAS	National Airspace System
NASIP	National Aviation Safety Inspection System
NCA	NVIS - Non-certificated Activity
NFD	Needs Further Definition
NNs	Neural Networks
NOPSS	National Operations Specification Subsystem
NPG	National Program Guidelines
NPRM	Notice of Proposed Rulemaking
NPTRS	National Program Tracking & Reporting System
NT	New Technology
NTSB	National Transportation Safety Board
NVIS	National Vital Information Subsystem
OASIS	Online Aviation Safety Inspection System
OATS	Office Automation Technology & Services
ODSS	Organizational Decision Support System
OLAP	On-line Analytical Processing
OPSS	Operations Specification Subsystem
ORD	Operations Requirements Document
PAI	Principal Avionics Inspector
PCD	Prototype Concept Document
PCI	Peripheral Connect Interface
PDS	Pilot Deviation Subsystem
PENS	Performance Enhancement System
PM	Performance Measure
PMI	Principal Maintenance Inspector
PMP	Program Management Plan
POI	Principal Operations Inspector
PRS	Parts Reporting System
PS	Policy System
PTRS	Program Tracking & Reporting System
Q & B	Query & Browse
Q & S	DoD Quality & Safety (Data)
R	Required
RAM	Random Access Memory
RAMPS	Regional Automated Mainframe Planning Subsystem
RAS	Remote Access Services
RCB	Requirements Change Board
RCM	Requirements Configuration Management
RCR	Requirements Change Request
RDMS	Relational Database Management System
REMIS	Reliability & Maintenance Information System
RI	DoD Ramp Inspections
ROLAP	Relational Online Analytical Processing
RPD	Research Project Description
RSPA	Research & Special Programs Administration
RTF	Rich Text Format
SAGA	*System Safety Approach* for General Aviation
SAI	System Attribute Inspection
SDR	Service Difficulty Report
SDRS	Service Difficulty Reporting System
SIESS	Simulator Inventory & Evaluation Schedule System
SPAS	Safety Performance Analysis System
SPERS	Safety Performance Evaluation Resource Scheduling, or
SPERS (DoD)	Survey & Performance Evaluation System
SRD	System Requirements Document
SRS	System Requirements Specification
SSDD	System Segment Design Document
SUPS	Suspected Unapproved Parts System
SVGA	Super Video Graphics Adaptor
TAC	Training & Automation Committee
TBD	To Be Determined
TCP/IP	Transmission Control Protocol/Internet Protocol
URL	Uniform Resource Locator
V & V	Verification & Validation
VADER	"VIS" & "DIS" Enterprise Repository
VIS	Vital Information System
WAN	Wide Area Network
WPIG	Work Program Interface Group

APPENDIX E - Illustrations (Full Size Drawings)

Figure 1. Decision Process

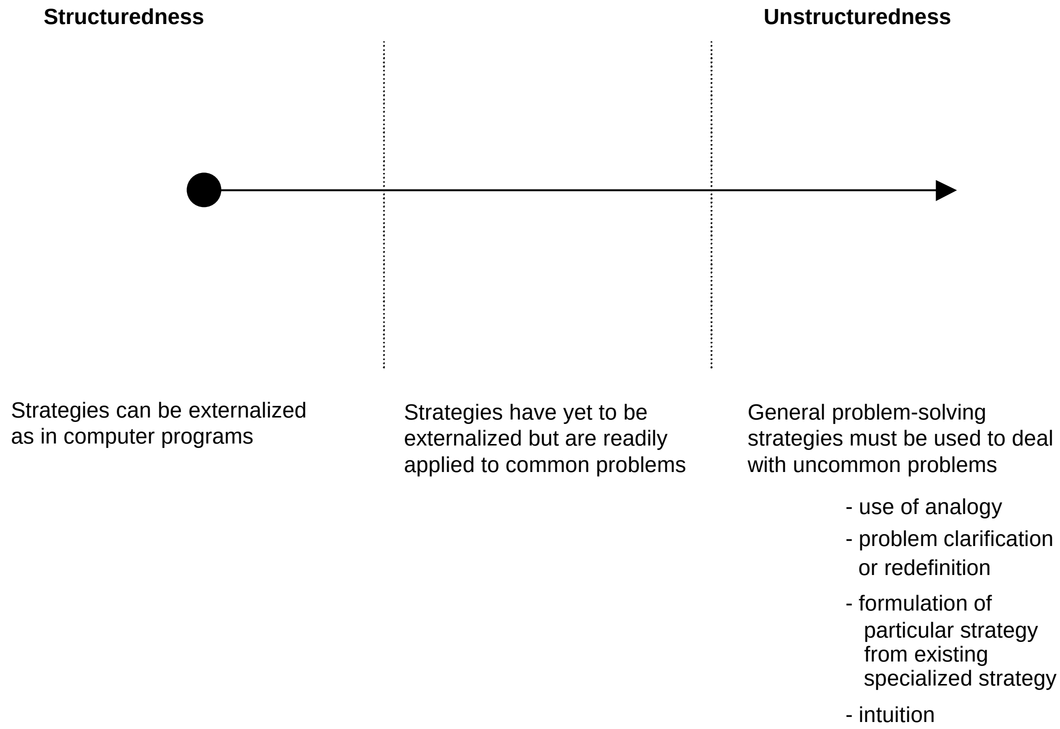

Figure 2. The Seven Facets of Decision Making

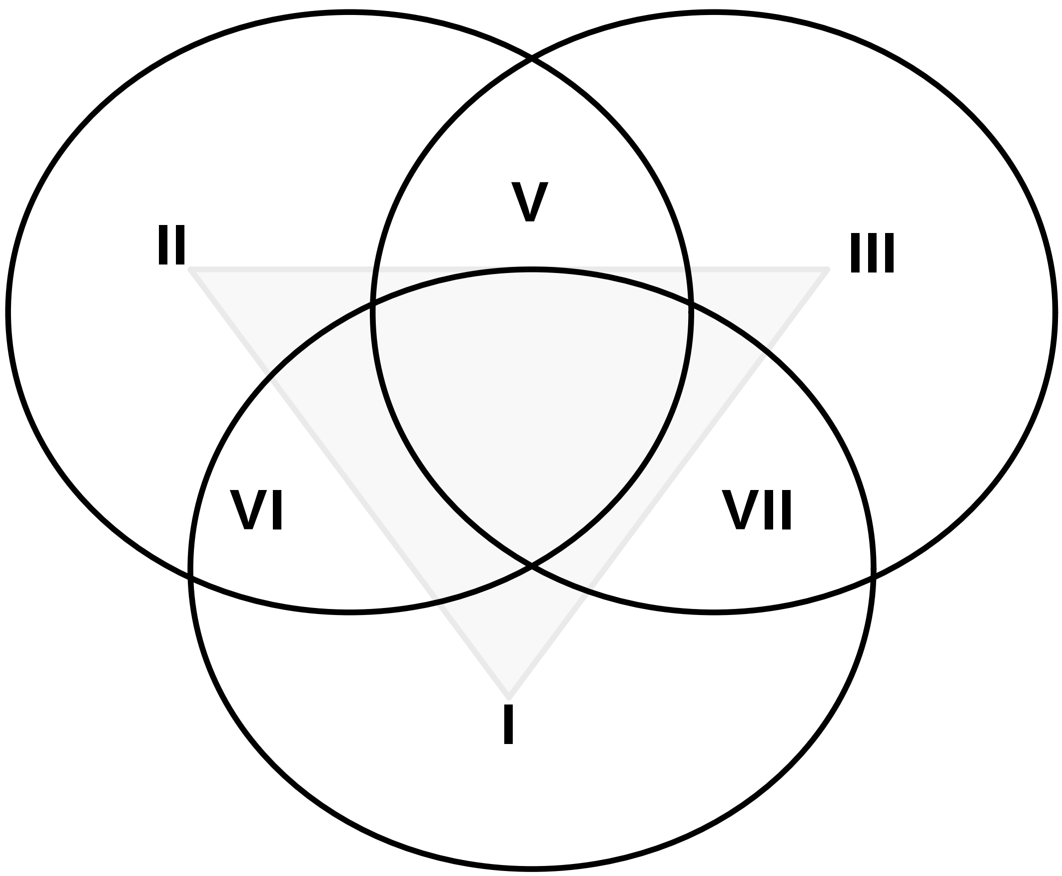

Figure 9. The seven facets of decision making. There are three (3) aspects of decision making (I, power; directive force. II, perspective; information collection. III, design; formulation of models) and four (4) attributes (IV, adaptation; continuous adjustment among the six other facets of decision making. V, analysis; continuing adjustment to perception, reality, and the process model. VI, idealism; continuing adjustment between power and perception. VII, implementation; continuing adjustment between plan and power). (1. Bonczek et. al.)

Figure 3. DSS Conceptual Framework

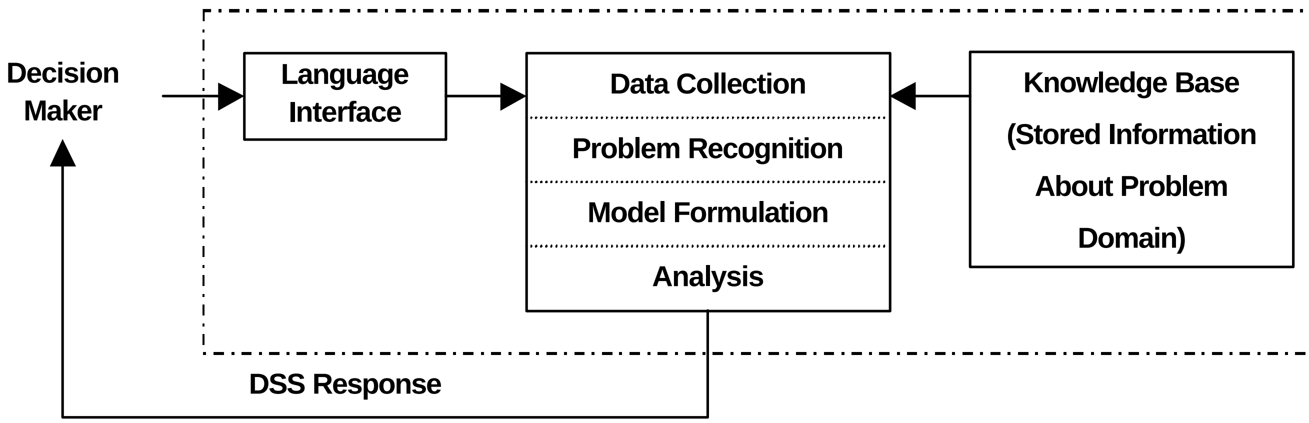

Figure 4. Data Pump

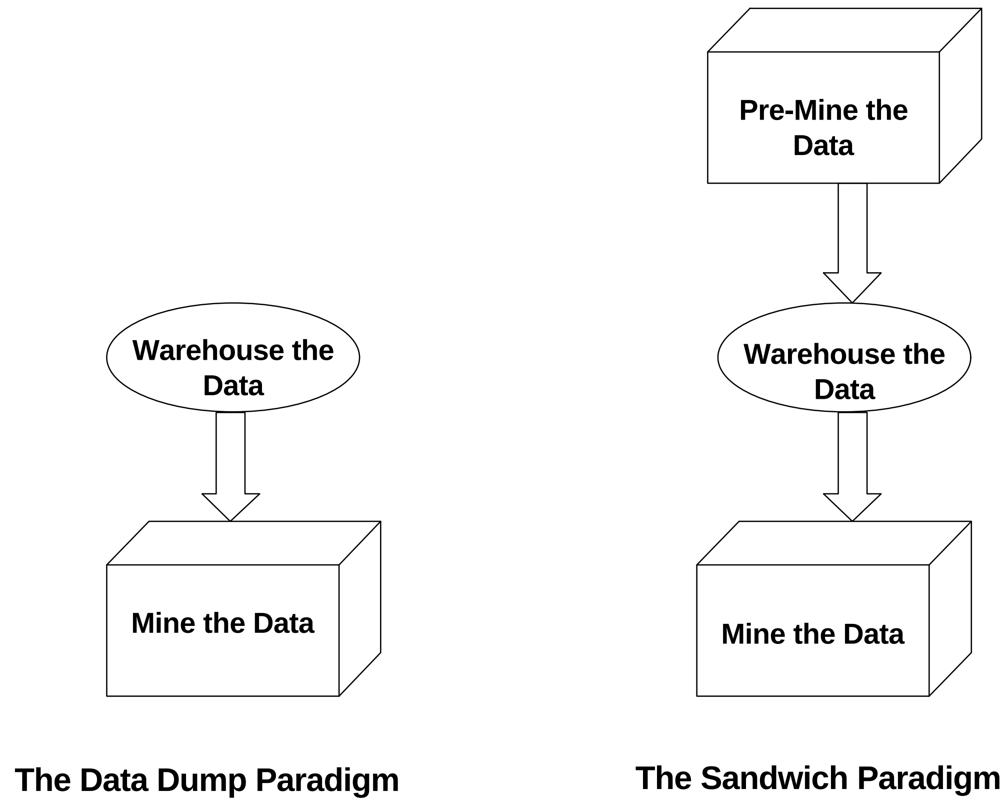

Figure 4.

Figure 5. Typical Data Warehouse Users

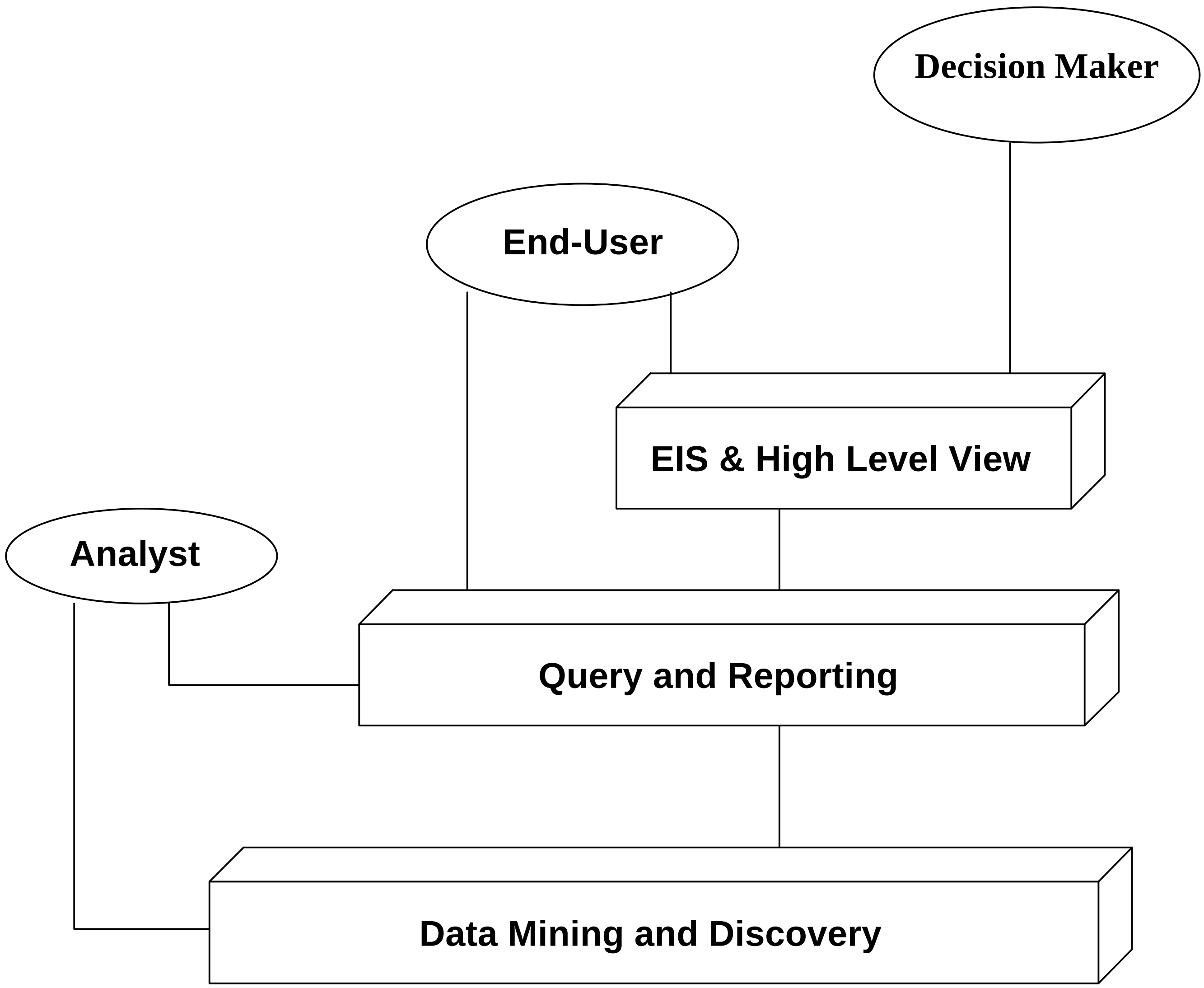

Figure 5. Typical Data Warehouse Users

Table 1. DSS Technology Matrix

Types of DSS Technology	Application Areas
Data Driven DSS Strengths: Access and manipulation of large databases, OLAP	File drawer and management reporting systems, data warehousing and analysis systems, Executive Information Systems (EIS) executive support systems (ESS). Business Intelligence.
Model Driven Strengths: simulation and optimization models, “What If” iterations. Some OLAP packages have modeling capabilities. Other than OLAPs , which use stored SQL procedures, This type DSS requires user input.	Accounting and financial ”what if,” “ trial and error” iterations. Good for solving common business and manufacturing type problems: scheduling, time series analysis or calculations, dealing with spatial oriented problems, and performing economic impact analysis based on formulas and user input.
Knowledge Driven Strengths: Possesses a domain knowledge base and inference engine. Modeling capabilities and natural language dialogue interface with users. Some have the ability to learn and develop independent data queries within its knowledge domain. Some are hyper-media enabled.	Expert System for specific knowledge domains, i.e., task or industry specific. Also capable of performing application functions that a Model Driven DSS can process. These systems have the facility to deal with problems that contain some degree of ambiguity. High degree of utility when alternatives are sought as part of the decision making process.
Document Driven Strengths: Hyper-media information retrieval capability. Workflow procedure that masks coding conventions that allow substantial to be accomplished non-IT staff	Information (document) retrieval system. Electronic forms and procedure automation. Collaboration through groupware facilities, e.g., virtual electronic meetings, joint document development, control geographically dispersed projects teams.
Communication Driven	N/A
General Purpose	N/A

Figure 6. DSS Planning & Implementing Model

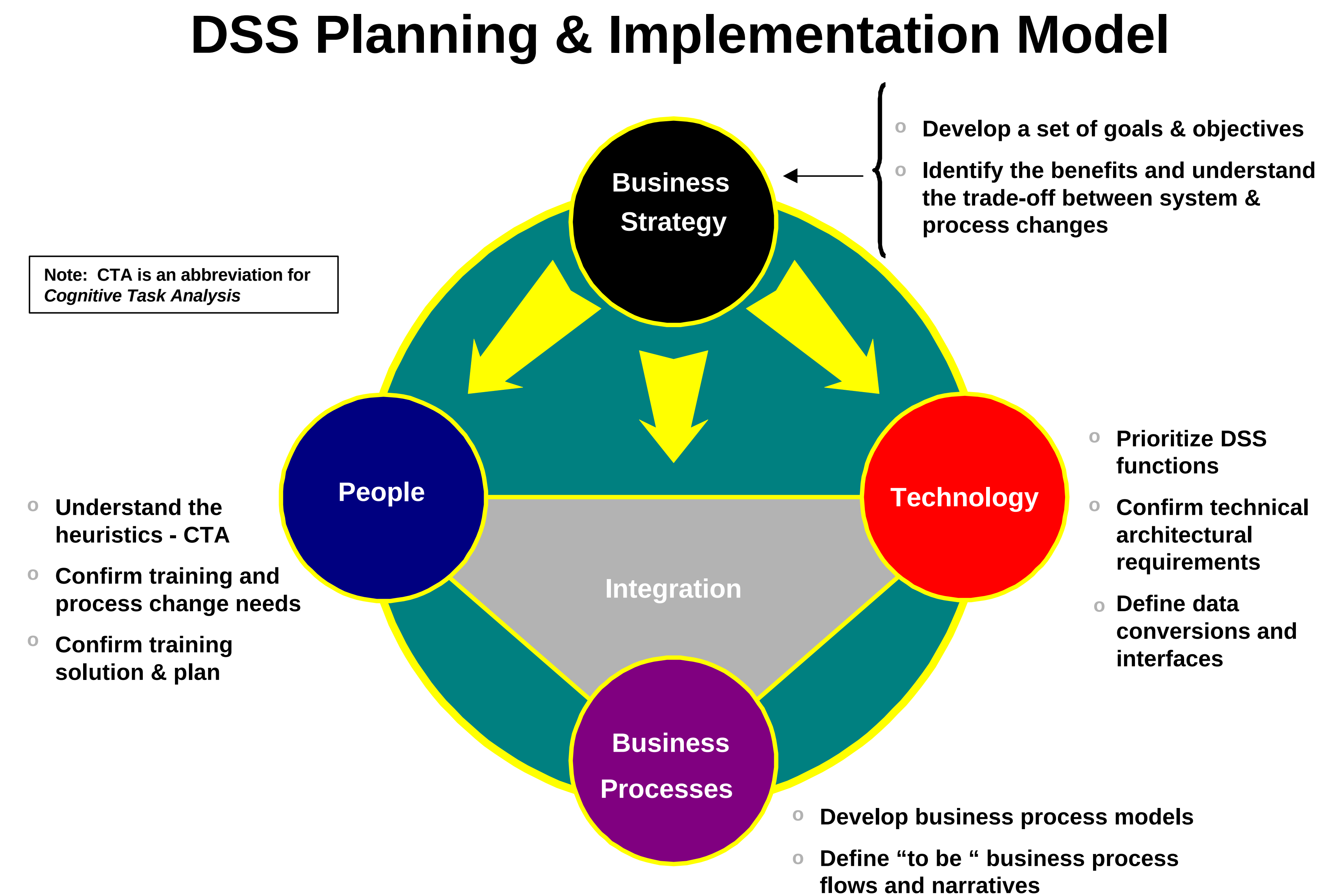

Figure 7. DSS Development Plan

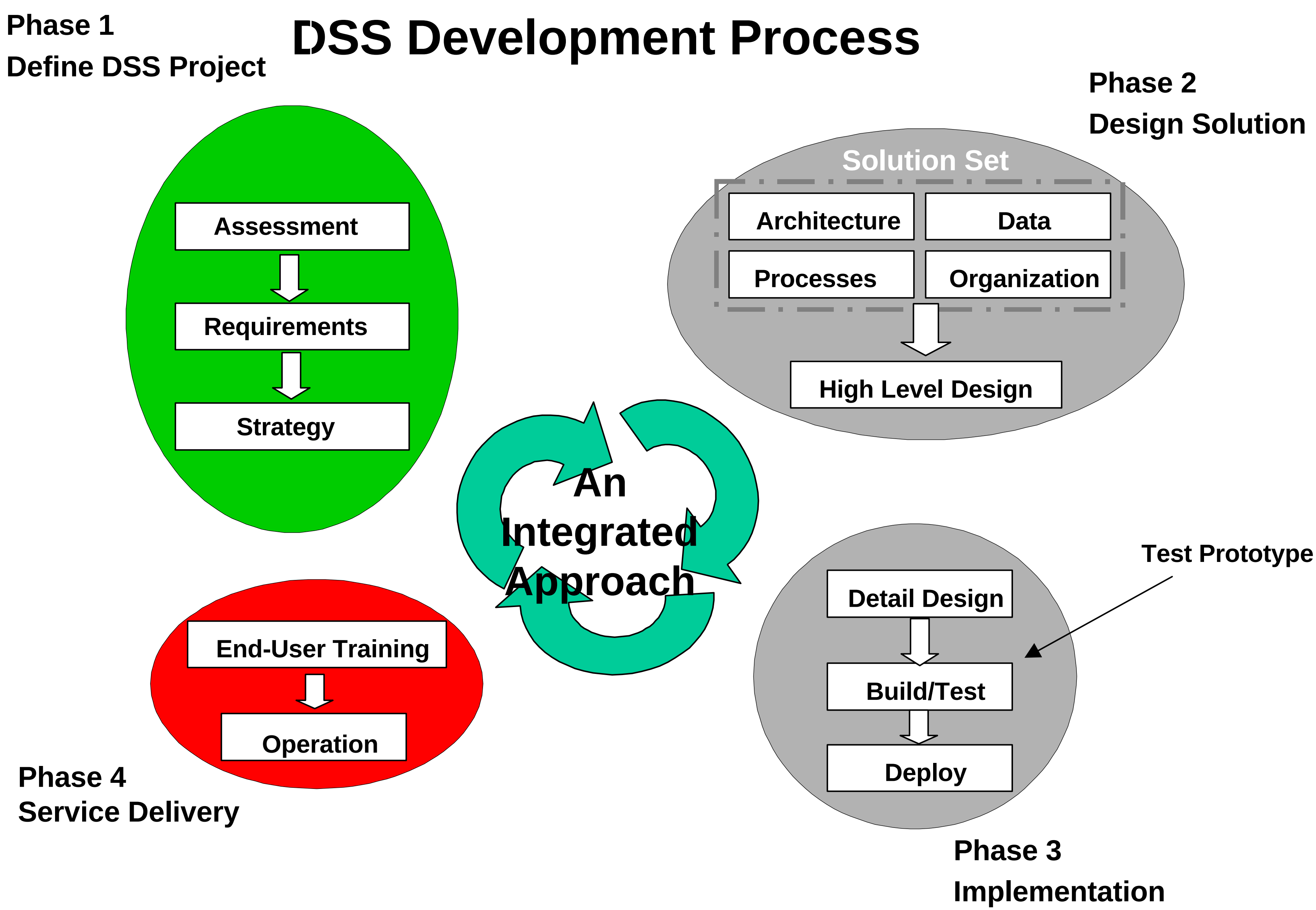

Figure 8. Knowledge-based DSS Model

Knowledge-based DSS Model

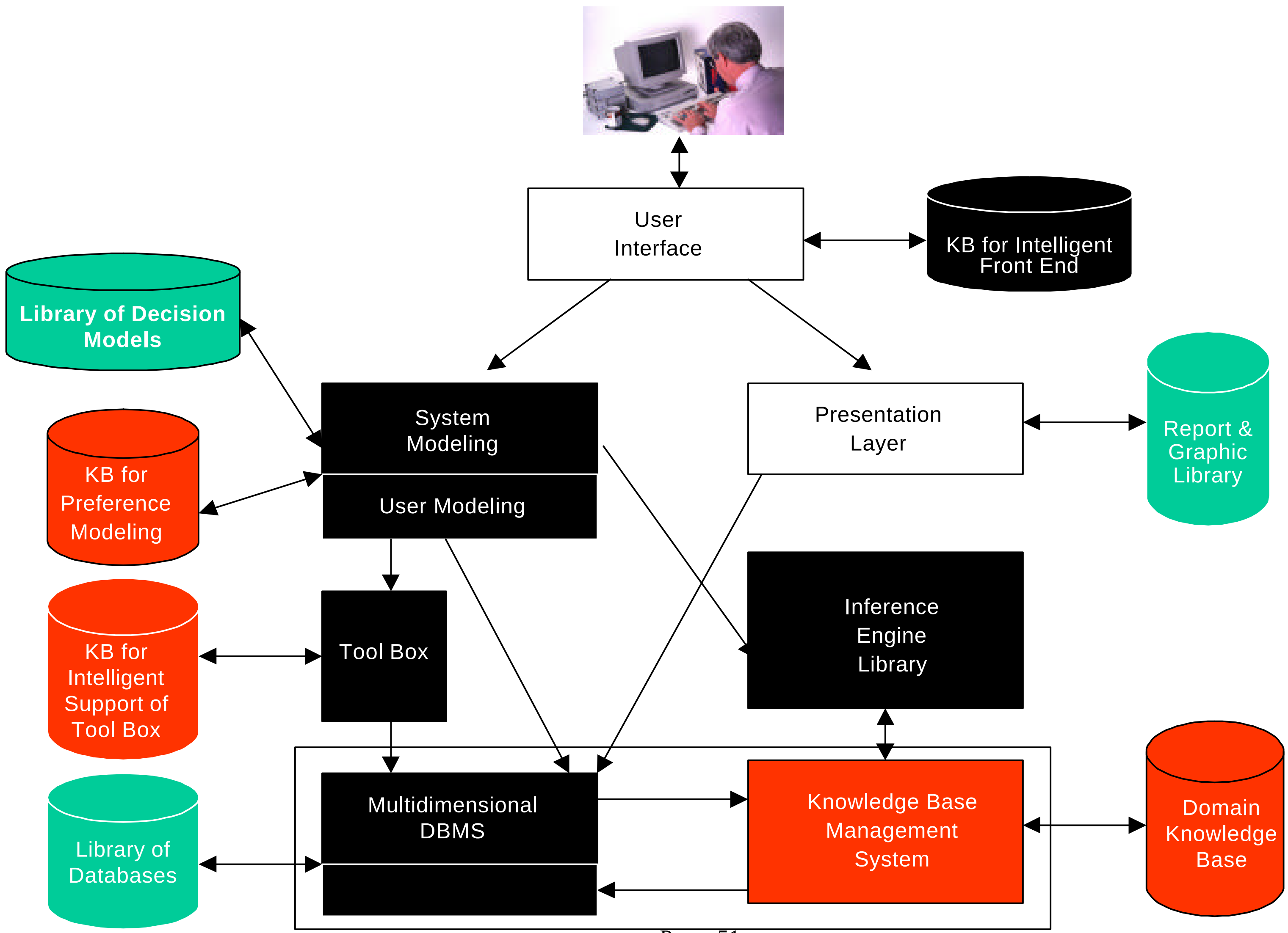

Figure 9. Semantic Data Model